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NUTRIENTS IN THE UPPER POTOMAC RIVER BASIN

Norbert A. Jaworski

Federal Water Pollution Control Administration
Annapolis, Maryland

August 1969

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Chesapeake Technical Support Laboratory
Middle Atlantic Region
Federal Water Pollution Control Administration
U. S. Department of the Interior

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NUTRIENTS IN THE UPPER POTOMAC RIVER BASIN

by

Norbert A. Jaworski

August 1969

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FOREWORD

In the past, engineers have been concerned primarily with two conventional parameters indicative of water quality, dissolved oxygen (DO) and coliform bacteria; and two wastewater treatment plant performance parameters, percentage removal of biochemical oxygen demand (BOD) and suspended solids (SS). These four parameters have been usually adequate to assess water quality conditions and to determine wastewater treatment requirements.

With the continued increase in population and associated industrial expansion, the waste assimilative capacity of some receiving waters are near or already have exceeded the maximum allowable to maintain water quality standards. Where this has occurred it has become essential to introduce new analytical parameters to assess water quality conditions, to re-evaluate conventional treatment methods, and also to investigate the long-term effects on water quality of other constituents in domestic, industrial, and agricultural discharges, such as nutrients, toxic metals, and pesticides.

The nutrients, especially phosphorus and nitrogen, that contribute to dense algal growth in the Potomac Estuary are currently being studied. A relationship between high nutrient content and accelerated eutrophication in the upper Potomac Estuary has been established. Therefore nutrient sources, their temporal and spatial distribution, and the transport mechanics of the Potomac River must be better understood.

CHAPTER II

INTRODUCTION

A. PURPOSE AND SCOPE

The Chesapeake Technical Support Laboratory (CTSL), Middle Atlantic Region, Federal Water Pollution Control Administration (FWPCA), has undertaken an extensive water quality management study of the Potomac River Basin. A significant part of this study has been to determine the sources of nutrients, their effects on water quality, and the development of a corrective program to achieve water quality standards.

To implement Recommendation Number 14 of the third session of the conference in the matter of pollution of the interstate waters of the Potomac and its tributaries in the Washington Metropolitan Area (District of Columbia-Maryland-Virginia), the Interstate Commission on the Potomac River Basin called a meeting for November 13-15, 1969, to consider the water quality problem of the entire basin. Emphasis is to be placed on the problem of nutrients, bacteria, sediments and pesticides and their effect on the Potomac Estuary.

This report is on the nutrient concentrations and loadings in the upper Potomac River Basin above Washington, D.C., and the purpose is:

1. To present data on the nutrient concentrations and loadings.
2. To identify the portions of the basin high in nutrients.

3. To describe the temporal and spatial distributions of the nutrients in the upper basin.
4. To determine relative nutrient concentrations attributed to domestic wastewater, industrial discharges, and land runoff.

A general report considering the nutrients in the entire basin is currently available [1].

B. ACKNOWLEDGEMENTS

The assistance and cooperation of various governmental and institutional agencies and industries in the basin greatly facilitated the collection and evaluation of the nutrient data. While every agency and industry contacted provided valuable assistance, the cooperation of the staffs of the following who participated in the sampling program merit special recognition:

Governmental Agencies:

Maryland Department of Water Resources
Maryland State Department of Health
U. S. Geological Survey, Department of the Interior
Washington Aqueduct Division, U. S. Corps of Engineers
Virginia State Water Control Board
West Virginia Department of Natural Resources
District of Columbia, Department of Public Health
District of Columbia, Department of Sanitary Engineering

Nutrient Network Stations:

Petersburg, West Virginia, Water Department
City of Romney, West Virginia
Hagerstown, Maryland, Water Department
Moorefield, West Virginia, Water Department
City of Shenandoah, Virginia

4<

Shepherdstown, West Virginia, Shepherdstown
Utilities Company
Luke, Maryland, West Virginia Pulp and Paper Company

Wastewater Treatment Plants:

Winchester, Virginia
Waynesboro, Virginia
Front Royal, Virginia
Staunton, Virginia
Hancock, Maryland
Pinto, Maryland
Cresaptown, Maryland
Bowling Green, Maryland
Cumberland, Maryland
Frederick, Maryland
Hagerstown, Maryland
Williamsport, Maryland
Upper Potomac River Commission, Westernport, Maryland
Celanese Fibers Company, Amcelle, Maryland

CHAPTER III

SUMMARY AND CONCLUSIONS

A 40-station stream sampling network was established for calendar year 1966, 35 of which were in the upper basin. Included in the sampling program were nutrient analyses of wastewater at 13 discharges in the basin. Nutrient and sediment data for this study were also obtained from other sources.

Based on the 1966 survey and other available data, the following were observed:

1. The annual average concentration of phosphorus as PO_4 in the major sub-basins varied from a minimum of 0.9 mg/l in the South Branch to a maximum of 1.9 mg/l in the Antietam watershed.

2. The annual average concentration of NO_2 + NO_3 nitrogen as N in the major sub-basins varied from 0.3 mg/l in the South Branch to 2.2 mg/l in Opequon Creek.

3. The annual average phosphorus and nitrogen concentrations in the smaller tributaries of the lower part of the basin near Washington, D.C., were about the same as those in the major upstream tributaries.

4. The annual average concentrations of phosphates, total Kjeldahl nitrogen (TKN) and NO_2 + NO_3 nitrogen in the freshwater stream flow entering the estuary near Washington, D.C., were 0.3, 0.3, and 0.9 mg/l, respectively.

5. The concentrations of inorganic nitrogen at most of the 35 non-tidal stations increased as the stream flow increased.

6. The concentrations of phosphorus and TKN at most of the 35 non-tidal stations remained fairly constant over wide ranges of stream flow.

7. Approximately 18,400 lbs/day of phosphorus as PO_4 and 10,700 lbs/day of total nitrogen (NO_2 + NO_3 and TKN) enter the streams of the upper basin from municipal and industrial discharges. This amounts to a daily per capita loading of 0.045 pounds of phosphorus and 0.026 pounds of nitrogen.

8. From an analysis of watersheds with varying land uses and receiving little or no wastewater discharges, the annual average nutrient loadings attributed to land runoff in the upper Potomac Basin were estimated to be 8,600 lbs/day of phosphorus and 43,900 lbs/day of nitrogen. The average annual yield per square mile was 0.8 lbs/day of phosphorus, 3.4 lbs/day of NO_2 + NO_3 nitrogen, and 0.5 lbs/day of TKN.

9. In the upper basin in 1966, about 70 percent of the total phosphorus entered the surface water from wastewater discharges with the remaining 30 percent from land runoff and other sources.

10. Approximately 80 percent of the estimated 54,400 lbs/day of total nitrogen (NO_2 + NO_3 and TKN) entering the surface waters of the upper basin in 1966 was from land runoff with the remaining 20 percent from wastewater discharges. Of the 43,800 lbs/day of total nitrogen from land runoff, about 27,100 lbs/day, or 62 percent, were from agricultural areas which comprise only 37 percent of the total drainage area in the upper basin.

11. The total phosphorus and NO_2 + NO_3 nitrogen loadings (lbs/day) are highly related to river discharge. For example, in August of 1966, with a river discharge of about 500 cfs, less than 1,000 lbs/day of total phosphorus as PO_4 and NO_2 + NO_3 nitrogen as N entered the estuary from the upper basin; while on February 14, 1966, with a flow greater than 40,000 cfs, about 217,000 and 354,000 lbs/day of PO_4 and NO_2 + NO_3 N, respectively, entered the estuary from the upper basin.

12. During low flow conditions a significant proportion of the phosphorus entering the surface water from the various sources in the upper basin is retained in the stream channel. At high stream flow, it appears that a large proportion of this phosphorus is "flushed" out of the stream channel and transported downstream.

13. Mass balances using the 1966 data indicated that about 37 percent of the phosphorus that entered the upper basin was retained in the stream channel. The long-term fate of this phorphorus retained in the channel bed is unknown.

14. On an average daily basis for 1966, the nutrient loadings entering the estuary from all sources in the upper basin were about 17,000; 49,000; and 5,700 lbs/day of total phosphorus as PO_4, NO_2 + NO_3 nitrogen as N, and TKN, respectively.

15. Wastewater discharges in the Washington, D.C., Metropolitan Area add about 63,000 lbs/day of total phosphorus as PO_4 and 54,000 lbs/day of total nitrogen mainly in the form of TKN to nutrient loadings in the upper Potomac Estuary.

16. During low flow periods over 90 percent of the total phosphorus and total nitrogen entering the upper estuary from all sources is from wastewater discharges in the Washington area.

17. Sampling stations in the Shenandoah and Monocacy River subbasins account for about 50 percent of the total phosphorus and 33 percent of the NO_2 + NO_3 nitrogen measured in the Potomac River at Great Falls, Maryland.

18. At five stations, sediment data collected by the United States Geological Survey indicated that the annual yield of sediment varied from 98 to 290 kilo-pounds (kips) per square mile with a total basin loading for 1966 of 1,897,000 kips. In 1961, the total basin loading was estimated to be 5,000,000 kips.

19. In 1966, the maximum stream flow occurred in February. During that time about 32 to 55 percent of the total annual sediment loadings were observed at the five sediment stations. Maximum nutrient loadings also occurred during the month.

20. The wide variation in nutrient loadings clearly demonstrates the need to sample more frequently over a wide range of stream flows before a precise identification of nutrient sources can be made.

CHAPTER IV

DESCRIPTION OF THE BASIN

From its headwaters on the eastern slopes of the Appalachian Mountains, the Potomac flows in a general southeasterly direction some 400 miles to Chesapeake Bay. The main stem is formed approximately 20 miles below Cumberland, Maryland, at the confluence of the North and South Branches of the Potomac and flows southeast to the Fall Line at Great Falls, Virginia. Below the falls at Chain Bridge, the lower river is tidal.

The Potomac River Basin has a drainage area of 14,670 square miles and encompasses parts of Pennsylvania, Maryland, West Virginia, and Virginia, and all of the District of Columbia. The major sub-basins including their drainage areas are:

Sub-basin	Drainage Area (square miles)
North Branch	1,328
South Branch	1,493
Cacapon River	683
Conococheague Creek	563
Opequon Creek	345
Antietam Creek	292
Shenandoah River	3,054
Monocacy River	970

The portion of the Potomac River above the Fall Line is about 266 miles long and follows a course through the mountainous terrain of the Alleghenies, across the fertile Ridge and Valley Province, through the Blue Ridge Mountains, and across the rolling hills of the Piedmont Plateau to the Fall Line and the Coastal Plain. It drains an area of about 11,500 square miles. It is a comparatively narrow, fast-flowing stream flanked by steep banks and mountains, and has many natural obstructions and rapids.

The average discharge of the Potomac River at Washington, D.C., is 11,340 cubic feet per second (cfs). Discharges of 484,000 cfs and less than 800 cfs have been recorded. The shape and character of the basin are such that they favor rapid runoff, with high discharges occurring for short periods of time and low flows existing for sustained periods during droughts. The Potomac River and its tributaries thus are characterized by flash floods and extremely low flows.

Of the 3 million people living in the basin, about 2.5 million, or 83 percent, live in the Washington, D.C., Metropolitan Area. The upper basin is largely rural with a scattering of small cities having populations of 10,000 to 20,000. Farming and related industries such as canning, fruit packing, tanning, and dairy products processing are major sources of income to the region.

There are coal mining activities in the North Branch sub-basin with industrial activity in the Westernport and Cumberland areas.

Industry has developed in the several small cities in the Potomac Basin and is expanding rapidly in the area between Waynesboro and Staunton and Front Royal along the South Fork of the Shenandoah River.

Land use in the entire Potomac Basin is estimated to be 5 percent urban, 55 percent forest, and 40 percent agriculture including pasture lands.

A map of the basin showing major municipal wastewater discharges is presented in Figure IV-1. A detailed inventory of the industrial and municipal wastewater discharges within the basin is contained in a separate report.

Some of the Nation's most popular recreational areas are in the basin. There are many historic and scenic attractions such as the Skyline Drive, the Appalachian Trail, limestone caverns, the Great Falls of the Potomac, and Civil War monuments.

The basin has abundant natural resources including coal, limestone, dolomite, glass sand, clay, hard and soft woods, and granite.

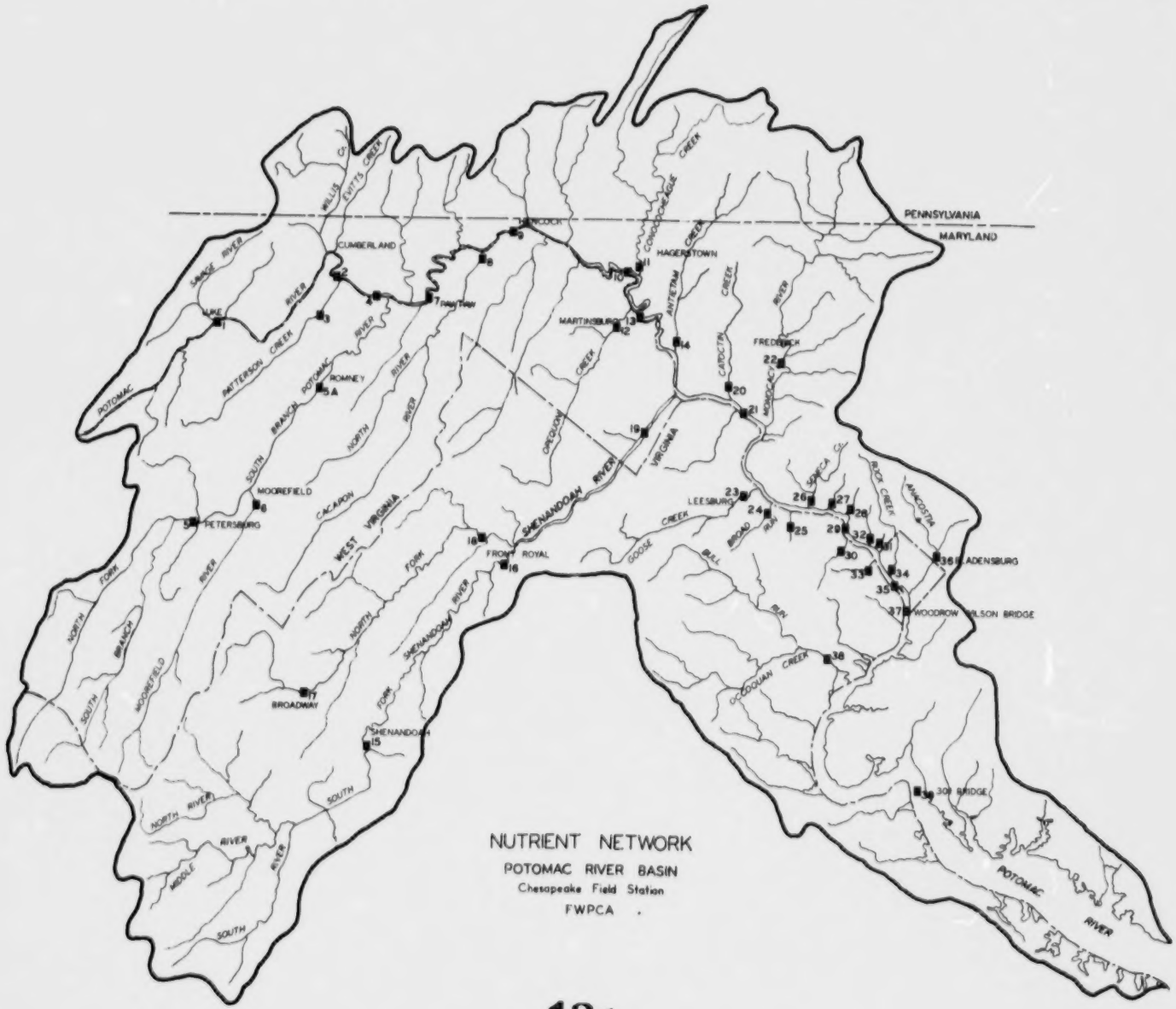

PENNSYLVANIA
MARYLAND
CUMBERLAND
HAGERSTOWN
MARTINSBURG
FREDERICK
ROMNEY
MOOREFIELD
PETERSBURG
FRONT ROYAL
LEESBURG
BROADWAY
SHENANDOAH
ADENSBURG
WOODROW WILSON BRIDGE
301 BRIDGE
POTOMAC RIVER
SHENANDOAH RIVER
WEST VIRGINIA
VIRGINIA
NUTRIENT NETWORK
POTOMAC RIVER BASIN
Chesapeake Field Station
FWPCA

Figure IV-1

CHAPTER V

DESCRIPTION OF SAMPLING PROGRAM AND OTHER DATA SOURCES

A. STREAM SAMPLING NETWORK

A stream sampling network was developed which consisted of 40 stations located strategically throughout the basin. The following criteria were used in locating the sampling stations:

1. At least one station in each major sub-basin representative of that sub-basin.
2. Where possible, sampling stations to be located at or near United States Geological Survey (USGS) gaging stations.
3. In the larger sub-basins, additional stations to be selected for areas having varying water and land uses.
4. In the Washington area, to determine the loading to the Potomac Estuary, all significant tributaries to be sampled.

A brief description of each sampling station is given in Table V-1 and the locations shown in Figure V-1. Samples were obtained weekly during the entire 1966 calendar year for most of the 40 stations.

Samples were analyzed for the following nutrients:

1. Nitrite-nitrate nitrogen
2. Organic nitrogen
3. Ammonia nitrogen

Table V-1

POTOMAC RIVER NUTRIENT NETWORK STATIONS

Station Number	Station Name	River	Location	USGS Gage Reference
1	Luke, Md.	N. Br. Potomac R.	West Virginia Pulp & Paper Co. Intake	1-5985
2	Cumberland, Md.	N. Br. Potomac R.	Bridge-Wiley Ford	1-6030
3	Fort Ashby	Patterson Creek	Just North of Fort Ashby-Rt. 28	1-6045
4	Oldtown, Md.	N. Br. Potomac R.	Toll Bridge-Oldtown	1-6100
5	Petersburg, W. Va.	S. Br. Potomac R.	U.S. Rt. 220 South of Petersburg	1-6065
5A	Romney, Va.	S. Br. Potomac R.	Rt. 50 Bridge West of Romney	1-6085
6	Moorefield, W.Va.	S. Br. Potomac R.	Moorefield Water Treatment Plant Intake	1-6080
7	Paw Paw, W.Va.	Upper Potomac R.	Rt. 51 Bridge, Paw Paw	1-6100
8	Great Cacapon, W.Va.	Cacapon River	Rt. 9 Bridge, Great Cacapon	1-6115
9	Hancock, Md.	Upper Potomac R.	Rt. 522 Bridge Hancock	1-6130
10	Hagerstown, Md.	Potomac River	Hagerstown Water Treatment Plant Above Williamsport	1-6130
11	Williamsport, Md.	Conococheague Cr.	Rt. 68 Bridge in Williamsport	1-6145

Table V-1 (cont.)

Station Number	Station Name	River	Location	USGS Gage Reference
12	Martinsburg, Va.	Opequon Creek	About 3 miles east of Martinsburg, Rt. 45 Bridge	1-6165
13	Shepherdstown, W.Va.	Potomac River	James Rumsey Bridge on Rt. 48 just North of Shepherdstown	1-6180
14	Antietam, Md.	Antietam Creek	Antietam Cr. Bridge near Confluence with Potomac River	1-6195
15	Shenandoah, Va.	S.F. Shenandoah R.	Shenandoah, Va.	1-6285
16	Front Royal, Va.	S.F. Shenandoah R.	At USGS Gaging Station near Front Royal	1-6310
17	Broadway, Va.	N.F. Shenandoah R.	Just North of Rt. 259	1-6320
18	Middletown, Va.	N.F. Shenandoah R.	Winchester Water Intake	1-6340
19	Bloomary, W.Va.	Shenandoah R.	Just under east side of Rt. 9 Bridge	1-6365
20	Brunswick, Md.	Catoctin Creek	About 4 miles east of Brunswick on Rt. 464 Bridge	1-6375

Table V-1 (cont.)

Station Number	Station Name	River	Location	USGS Gage Reference
21	Point of Rocks, Md.	Potomac River	U.S. Rt. 15 Bridge	1-6385
22	Frederick, Md.	Monocacy River	Reels Mill Road Bridge	1-6430
23	Leesburg, Va.	Goose Creek	Rt. 7 Bridge	1-6440
24	Broad Run, Md.	Broad Run	Rt. 7 Bridge	1-6450
25	Leesburg, Va.	Sugarland Run	Rt. 7 Bridge	1-6450
26	Seneca, Md.	Seneca Creek	River Road Bridge Rt. 190	1-6450
27	Travilah, Md.	Muddy Branch	River Road Bridge	1-6450
28	Beall Mount, Md.	Watts Branch	River Road Bridge	1-6452
29	Great Falls, Md.	Potomac River	Just west of MacArthur Blvd.	1-6465
30	Great Falls, Va.	Difficult Run	Rt. 193 Bridge	1-6460
31	Cabin John, Md.	Cabin John Cr.	George Washington Memorial Pkwy. Bridge-just east of D.C. Beltway Rt. 495	1-6450

Table V-1 (cont.)

Station Number	Station Name	River	Location	USGS Gage Reference
32	Caderock, Md.	Rock Run	Just off MacArthur Blvd. west of Rt. 495	1-6452
33	Arlingwood, Va.	Pimmit Run	Rt. 120 Bridge, Intersection of Rt. 120 and Rt. 123	1-6467
34	Mst. Bridge, D.C.	Rock Creek	M. St. Bridge	1-6480
35	14th St., D.C.	Potomac River	14th St. Bridge (Boat Sta. #1)	1-6465
36	Bladensburg, Md.	Anacostia River	U.S. Hwy Rt. Bridge	1-6495 (Riverdale) 1-6510 (Hyattsville)
37	Woodrow Wilson Bridge	Potomac River	Boat Sta. #5	1-6465
38	Occoquan, Va.	Occoquan Creek	Above Bridge, Rt. 123 Va.	1-6570
39	301 Bridge	Potomac River	301 Bridge	1-6465

PENNSYLVANIA
MARYLAND
LEGEND OF TREATMENT
NONE
PRIMARY
INTERMEDIATE
SECONDARY (LAGOON)
TERTIARY
MAJOR MUNICIPAL WASTEWATER DISCHARGES
POTOMAC RIVER BASIN
Chesapeake Field Station
FWPCA

Figure V-1

4. Total Kjeldahl nitrogen

5. Total phosphorus

B. WASTEWATER TREATMENT PLANT DATA

During the midsummer of 1966, the sampling program was expanded to weekly measurements of nitrogen and phosphorus in 13 of the major wastewater discharges of the upper basin. For a period of six months, nutrient analyses were made of both the influent and effluent at each wastewater treatment facility. A list of facilities sampled is given in Table V-2.

A survey was made of all major wastewater treatment facilities in the upper Potomac River Basin in 1968. All municipal and biodegradable industrial wastewater discharges with a flow greater than 0.5 mgd were sampled. In the Washington Metropolitan Area, nutrient analyses at the large wastewater facilities are made routinely.

C. SEDIMENT DATA

At five of the nutrient network stations, sediment loading is routinely monitored by the USGS. The five sediment stations are listed in Table V-3.

Sediment loading to the Potomac Estuary at Great Falls, Maryland, was calculated by totaling the loading from the Monocacy River and the Potomac River at Point of Rocks, Maryland.

Table V-2

WASTEWATER TREATMENT FACILITIES SAMPLED FOR NUTRIENTS
POTOMAC RIVER BASIN

Name	Type of Plant	Type of Waste*	Flow	Type of Treatment	% of BOD Removal
Bel-Air - Pinto, Md.	Lagoon	San.	0.030	Secondary	70%
Bowling Green, Md.	Settling	San.	0.206	Primary	35%
Celanese Corp. (Amcelle, Md.)	Lagoon	Ind.	2.300	Primary	XX%
Cresaptown, Md.	Settling	San.	0.070	Primary	35%
Cumberland, Md.	Settling	San. & Ind.	9.300	Primary	35%
Frederick, Md.	Trickling Filter	San. & Ind.	4.600	Secondary	75%
Front Royal, Va.	Settling	San.	1.200	Primary	35%
Hagerstown, Md.	Activated Sludge	San. & Ind.	5.852	Secondary	56%
Staunton, Va.	Trickling Filter	San.	2.600	Secondary	85%
Waynesboro, Md.	Trickling Filter	San.	2.715	Secondary	80%
Westernport, Md. (Upper Pot. R. Comm.)	Activated Sludge	San. & Ind.	21.720	Secondary	85%
Williamsport, Md.	Settling	San.	0.233	Primary	35%
Winchester, Md.	Trickling Filter	San. & Ind.	4.200	Secondary	85%

* If two types indicated, the first is of primary importance.

Table V-3

USGS SEDIMENT STATIONS
Potomac River Basin

Station	Stream
Point of Rocks, Md.	Potomac River
Jug Bridge near Frederick, Md.	Monocacy River
Fairview, Md.	Conococheague Creek
Cumberland, Md.	North Branch Potomac River
Colesville, Md.	Northwest Branch Anacostia River

D. DALECARLIA WATER FILTRATION PLANT DATA, U. S. CORPS OF ENGINEERS

The raw water supply at Great Falls, Maryland, for the Washington Metropolitan Area is monitored for various chemical and sanitary parameters including nutrients. In 1969, the analyses conducted by the U. S. Corps of Engineers were expanded to include three forms of phosphorus and four forms of nitrogen.

CHAPTER VI

SOURCES OF NUTRIENTS (PHOSPHORUS AND NITROGEN)

A. WASTEWATER DISCHARGES

Nutrient loadings and wastewater treatment plant efficiencies of 13 facilities were determined weekly for six months. Excluding the Amcelle and Westernport plants, which receive industrial waste principally, the average concentrations and removal efficiencies are given below:

Parameter	Influent (mg/l)	Effluent (mg/l)	Removal (%)
T. PO_4 as PO_4	39.0	29.4	25.0
NO_2 as N	0.1	0.7	-
NO_3 as N	0.1	0.2	-
TKN as N	21.1	16.4	22.0

As shown in the above tabulation, the average removal of phosphorus was about 25 percent and the average TKN removal was 22 percent. The nitrite and nitrate loadings to the plants were insignificant. (Summary data for individual facilities are given in Table B-5.)

As of December 1968, there were 256 wastewater discharges in the upper Potomac River Basin [2] . Based on a survey of the major wastewater treatment facilities, it was estimated that about 18,430 lbs/day of TPO_4 and 10,680 lbs/day of TKN were discharged to the surface waters (Table VI-1). For a sewered population of 403,500, this amounts to a per capita loading of 0.045 lbs/day of phosphorus and 0.026 lbs/day of nitrogen.

Table VI-1

NUTRIENT LOADINGS FROM WASTEWATER DISCHARGES
BY SUB-REGIONS

Sub-Region	Population Served	LOADING AFTER TREATMENT BOD lbs/day	TKN lbs/day	TPO_4 lbs/day
North Branch	79,200	55,300	1750	4850
South Branch and Upper Region	17,300	2,720	370	460
Opequan	34,800	3,470	480	1100
Conococheague and Upper-Middle Region	26,900	4,250	710	1050
Antietam and Middle Region	61,500	7,980	890	2380
Shenandoah	108,500	31,800	4890	6360
Catoctin Creeks Md. and Va.	5,400	740	110	220
Monocacy	62,500	4220	1380	1830
Lower Region	7,400	200	100	180
TOTAL	403,500	110,680	10,680	18,430

* A Sub-Region may include discharges to the small tributaries and to the main stem of the Potomac.

Of the nine sub-regions (Table VI-1), the largest source of nutrients is the Shenandoah watershed. About 35 percent of the TPO_4 and 45 percent of the TKN in the upper basin originates in this watershed.

Nutrient loadings from industrial wastewater discharges are about 7,700 lbs/day of TPO_4 and 4,600 lbs/day of TKN. The industrial contribution to the total wastewater nutrient loadings in the upper basin is about 42 percent for the total PO_4 and about 43 percent of the total nitrogen. The amount of NO_2 + NO_3 nitrogen in both the industrial and municipal wastewater discharges is insignificant.

B. LAND RUNOFF AND OTHER SOURCES

To determine the amount of nutrients coming from land runoff, analyses of loadings from three distinct land uses (forest, agricultural, and urban) were made. Using the Catoctin Creek, Maryland, watershed basin as primarily agricultural, the Patterson Creek watershed as forested, and Rock Creek watershed as urban, the effect of land uses on the concentration of nutrients in the surface waters is illustrated in Figures VI-1 and VI-2. The watersheds above the sampling stations in these three areas receive a relatively small volume of wastewater.

In the Patterson Creek watershed, the concentrations of both phosphorus and inorganic nitrogen were the lowest for the three types of land uses. For an agricultural area such as the Catoctin Creek watershed, the concentrations of nutrients were higher and fluctuated

LAND USE COMPARISON

TOTAL PHOSPHORUS PO_4

POTOMAC RIVER BASIN

1966

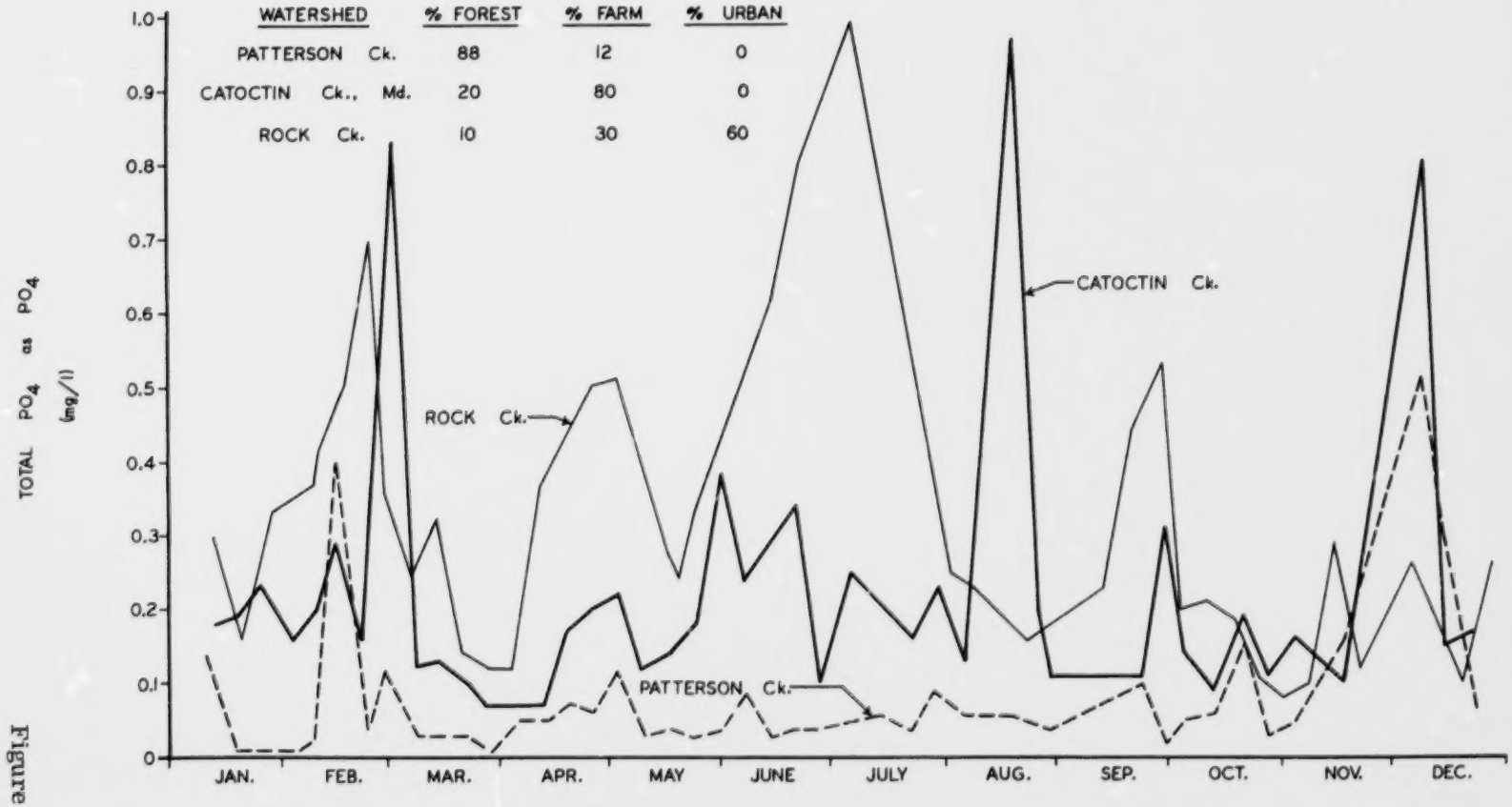


Figure VI-1

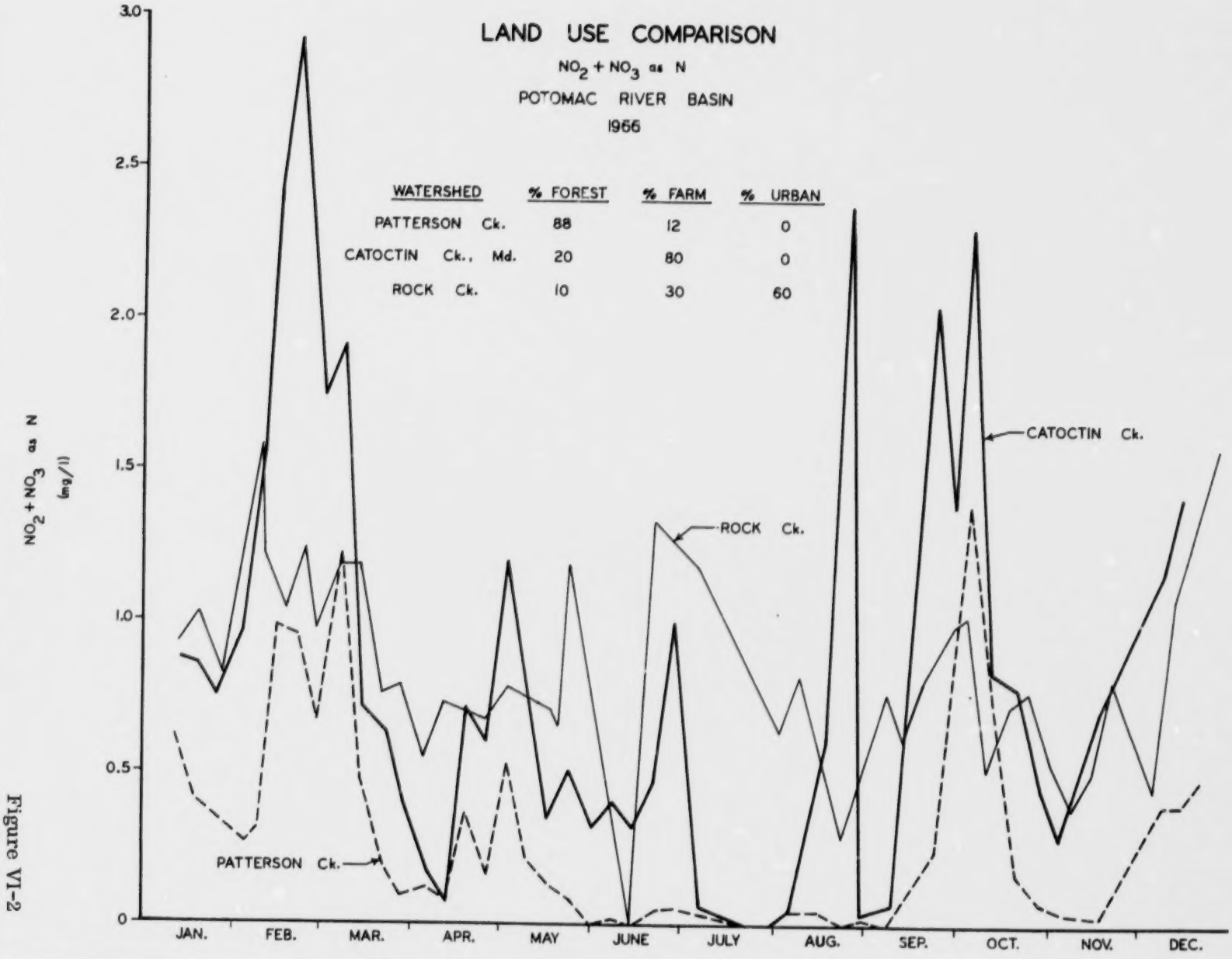

LAND USE COMPARISON
$NO_2 + NO_3$ as N
POTOMAC RIVER BASIN
1966
WATERSHED | % FOREST | % FARM | % URBAN
PATTERSON Ck. | 88 | 12 | 0
CATOCTIN Ck., Md. | 20 | 80 | 0
ROCK Ck. | 10 | 30 | 60
$NO_2 + NO_3$ as N (mg/l)
3.0
2.5
2.0
1.5
1.0
0.5
0
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEP.
OCT.
NOV.
DEC.
CATOCTIN Ck.
ROCK Ck.
PATTERSON Ck.

Figure VI-2

considerably. The high NO_2 + NO_3 concentrations were observed during periods of high stream flow conditions.

The high variation in NO_2 + NO_3 nitrogen can be attributed to high mobility of NO_3 ion as reported by Wadleigh [3] and Bailey [4]. Figure VI-3 for the South Branch station at Petersburg demonstrates that the concentration of nitrates is directly related to river discharge while concentrations of TKN and PO_4 are indirectly related.

For the 35 stations in the non-tidal portion of the basin, regression analyses were made using both linear and log transforms. The log transforms appeared to yield the best correlation resulting in the following expression:

$$C = aQ^b$$

where:

C = concentration of PO_4, TKN, or NO_2 + NO_3 (mg/l)

Q = stream flow (cfs)

a = a constant

b = an exponent

Using the slope of the concentration-discharge relationship (the exponent b) and knowing the specific location of the sampling point in relation to the municipal or industrial waste outfalls, a quantization of the sources of the nutrients can be obtained. For example, all stations, except one below an industrial outfall discharging nitrates, had a positive slope ranging from about 0.3 to 0.7 with an average of 0.5 suggesting that most of the inorganic nitrogen comes from land and other sources and not from wastewater discharges.

SOUTH BRANCH POTOMAC RIVER

AT

PETERSBURG, WEST VIRGINIA

TKN, $NO_2 + NO_3$ and PO_4 Vs. RIVER DISCHARGE

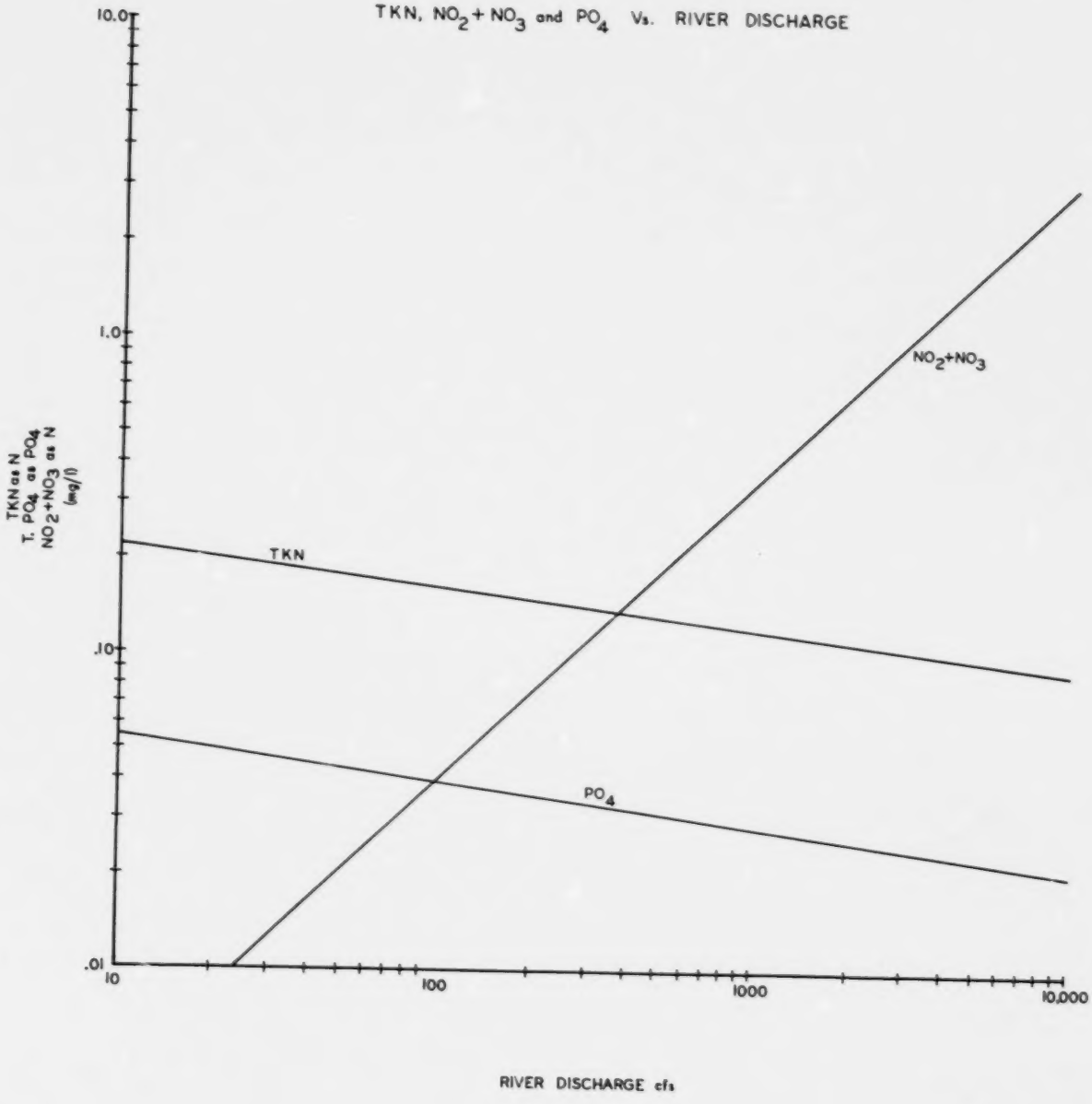


Figure VI-3

The concentrations of phosphorus and TKN for most of the non-tidal stations had either slightly positive or negative slopes indicating a diluting effect. The correlation coefficients for these two parameters were low, probably due to seasonal and flushing effects.

However, the slope of the relationship for stations above and below waste outfalls definitely supports the findings of Bailey [4] which indicate that (1) phosphorus and organic nitrogen have low mobility in soil, (2) PO_4 and TKN are not readily leached, and (3) concentration appears to be related to wastewater loadings and stream transport mechanisms.

The average annual yields of phosphorus and nitrogen based on the survey data for the three watersheds are given in Table VI-2.

Table VI-2

NUTRIENT LOADINGS FROM WATERSHEDS WITH VARYING LAND USE

Watershed and Land Use	Drainage Area (sq.mi.)	TPO_4 as PO_4 (lbs/day/sq.mi.)	$NO_2 + NO_3$ as N (lbs/day/sq.mi.)	TKN as N (lbs/day/sq.mi.)
Patterson Creek (Forest)	279	0.50	2.02	0.41
Catoctin Creek (Agric.)	109	1.25	5.30	0.65
Rock Creek (Urban)	77	1.10	2.70	0.67

Table VI-2

NUTRIENT LOADINGS FROM WATERSHEDS WITH VARYING LAND USE

Watershed and Land Use	Drainage Area (sq.mi.)	T. PO_4 as PO_4 (lbs/day/sq.mi)	NO_2 + NO_3 as N (lbs/day/sq.mi)	TKN as N (lbs/day/sq.mi.)
Patterson Creek (Forest)	279	0.50	2.02	0.41
Catoctin Creek (Agric.)	109	1.25	5.30	0.65
Rock Creek (Urban)	77	1.10	2.70	0.67

Similar nutrient levels and seasonal variations were also observed for watersheds having comparable land uses without large wastewater discharges.

For the Monocacy and Conococheague sub-basins, inorganic nitrogen yields of over 10 lbs/day/sq. mile were measured. The high yields can be attributed partly to land runoff and feed lot drainage. At times farm animals can be seen wading in many of the small tributaries of the Monocacy.

Using the same land use designation as the U.S. Corps of Engineers in the 1958 study [5], the nutrient loading from land runoff was determined and is shown in Table VI-3. It is noted that 64 percent of the nutrients from land runoff is from agricultural areas even though over 62 percent of the basin is covered by forest.

Table VI-3

ESTIMATED NUTRIENT LOADINGS FROM LAND RUNOFF

UPPER POTOMAC RIVER BASIN

Land Use	Area	T. PO_4 as PO_4		$NO_2 + NO_3$ as N		TKN as N	
	(sq. mi.)	(lbs/day/sq. mi.)	(lbs/day)	(lbs/day/sq. mi.)	(lbs/day)	(lbs/day/sq. mi.)	(lbs/day)
Agriculture*	4100	1.25	5100	6.0	24,500	0.65	2660
Forest	6800	0.50	3400	2.0	13,600	0.40	2720
Urban	100	1.10	110	3.0	300	0.65	65
Total upper Basin	11000	0.78	8610	3.20	38,400	0.50	5445

* Agricultural use includes both crop land and pastures.

CHAPTER VII

ANALYSES OF NUTRIENT NETWORK DATA

The data from the 1966 nutrient network stream sampling stations are presented in a detailed report [6]. A computer program especially designed for the survey was developed to aid in analyzing the data which are presented in three forms as follows:

1. Sampling station information
2. Input data (observed data)
3. Loading data (calculated information from input data)

Monthly summaries of the nitrogen and phosphorus data are presented in Appendix B.

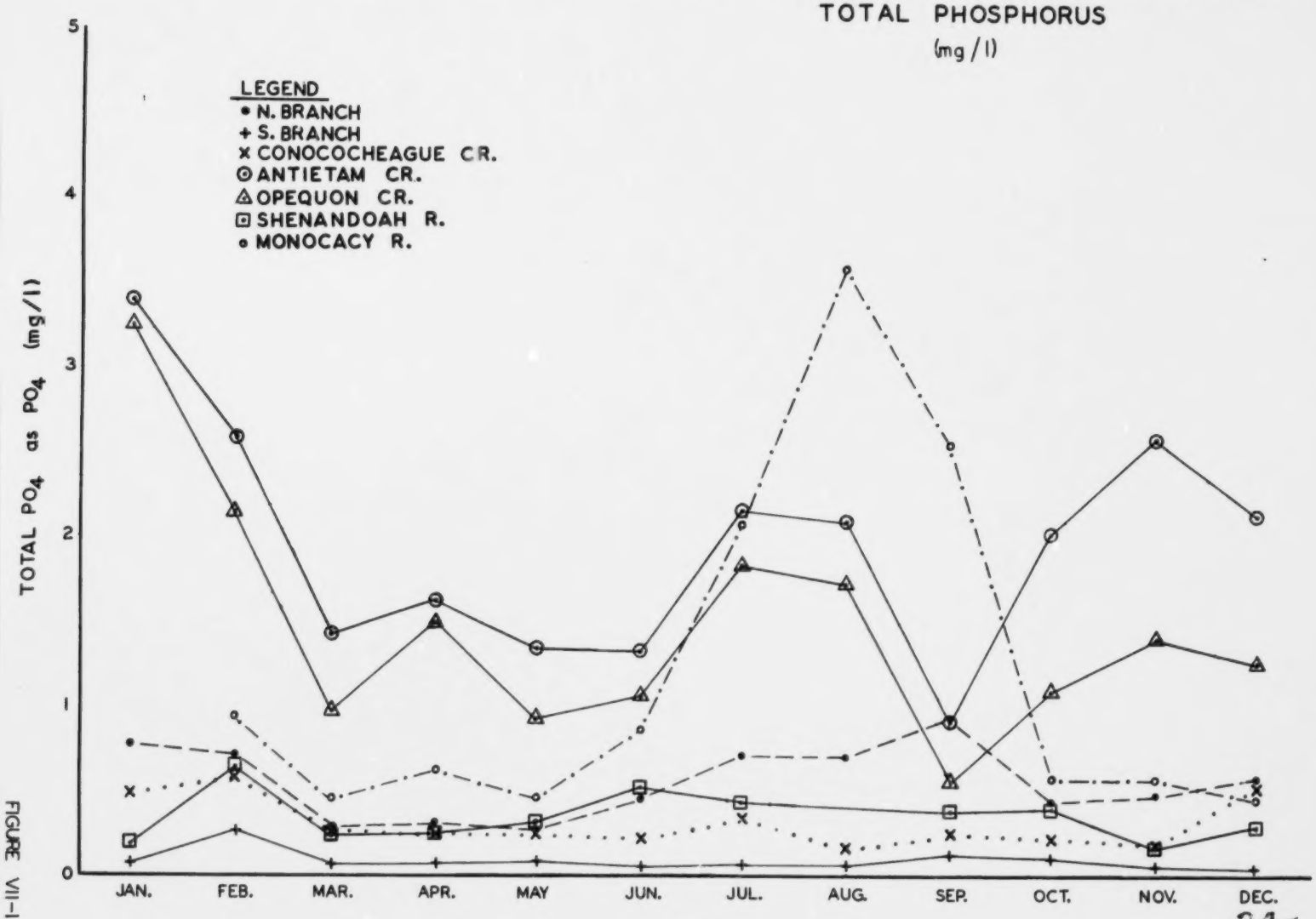
The results of the nutrient network survey have been grouped into three areas (1) major sub-basins of the upper basin, (2) the main stem of the Potomac, and (3) tributaries of the lower region near Washington, D.C. Only data from the key stations of these areas are discussed separately below.

A. PHOSPHORUS

1. Major Sub-basins of the Upper Potomac Basin (North Branch, South Branch, Conococheague, Antietam, Opequon, Shenandoah, and Monocacy Watersheds)

Figure VII-1 and Table VII-1 indicate the concentration of phosphorus to be about five times greater in the Monocacy River, Opequon Creek, and Antietam Creek sub-basins than in the remaining four basins. These higher concentrations are also reflected in large yields of 2 to 4 lbs/day/sq. mile, as shown in Table VII-1.

MAJOR SUB-BASINS of POTOMAC RIVER BASIN
TOTAL PHOSPHORUS
(mg/l)



1966

FIGURE VII-1

Table VII-1

COMPARISON OF PHOSPHORUS CONCENTRATIONS AND LOADINGS
FOR THE MAJOR SUB-BASINS

Sub-basin (Station)	T. PO_4 as PO_4 (mg/l)	(lbs/day)	(lbs/day/sq. mi.)
North Branch (Oldtown, Md.)	.352	2,551	1.92
South Branch (Romney, W. Va.)	.092	1,535	1.06
Conococheague Creek (Williamsport, Md.)	.327	1,226	2.61
Antietam Creek (Antietam, Md.)	1.996	1,353	4.78
Opequon Creek (Martinsburg, W. Va.)	1,511	1,109	3.59
Shenandoah River (Bloomery, W. Va.)	.356	5,105	1.68
Monocacy River (Frederick, Md.)	1.176	3,385	4.16
Potomac River (Great Falls, Md.)	.379	17,013	1.48

The phosphorus concentration displays a fairly consistent seasonal pattern, low in months of high flow and higher during dry periods. (See Figure VII-2 for monthly average stream flows for select gaging stations.)

As summarized in Table VII-1 and exhibited in Figure VII-3, the loading (pounds/day) for the major sub-basins follows the seasonal pattern of the river discharge. The large increase in September 1966, as shown in Figure VII-3, is a result of extremely high river discharges during this month.

2. Main Stem

As presented in Figure VII-4 and in Table VII-2, the phosphorus concentrations for stations along the main stem are greatly affected by the phosphorus levels in the sub-basins. The high concentrations of phosphorus in the Antietam, Opequon, and Monocacy watersheds are diluted by main stem flows.

The phosphorus concentration appears to vary inversely to stream flow as did the phosphorus levels in the sub-basins (Figure VI-3). The relatively high levels in September for Oldtown and Great Falls which had fairly high stream flows are probably due to a flushing action of river channel.

The phosphorus loadings during the low flow months of June, July, and August of 1966 were less than one-fourth of the loading for the remaining months. This seasonal variation is apparent in Figure VII-5.

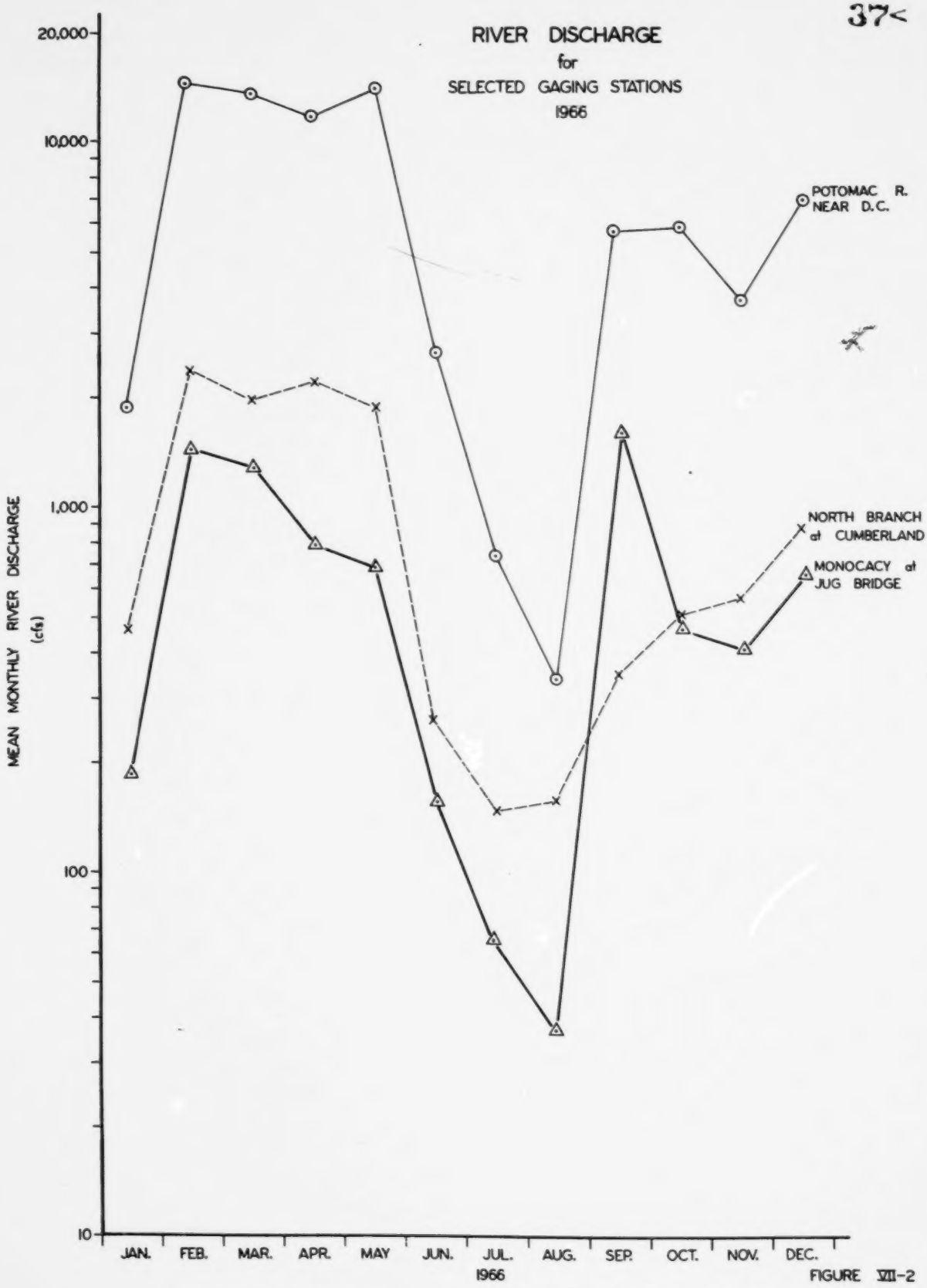

RIVER DISCHARGE
for
SELECTED GAGING STATIONS
1966
20,000
10,000
1,000
100
10
MEAN MONTHLY RIVER DISCHARGE (cfs)
POTOMAC R. NEAR D.C.
NORTH BRANCH at CUMBERLAND
MONOCACY at JUG BRIDGE
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1966

FIGURE VII-2

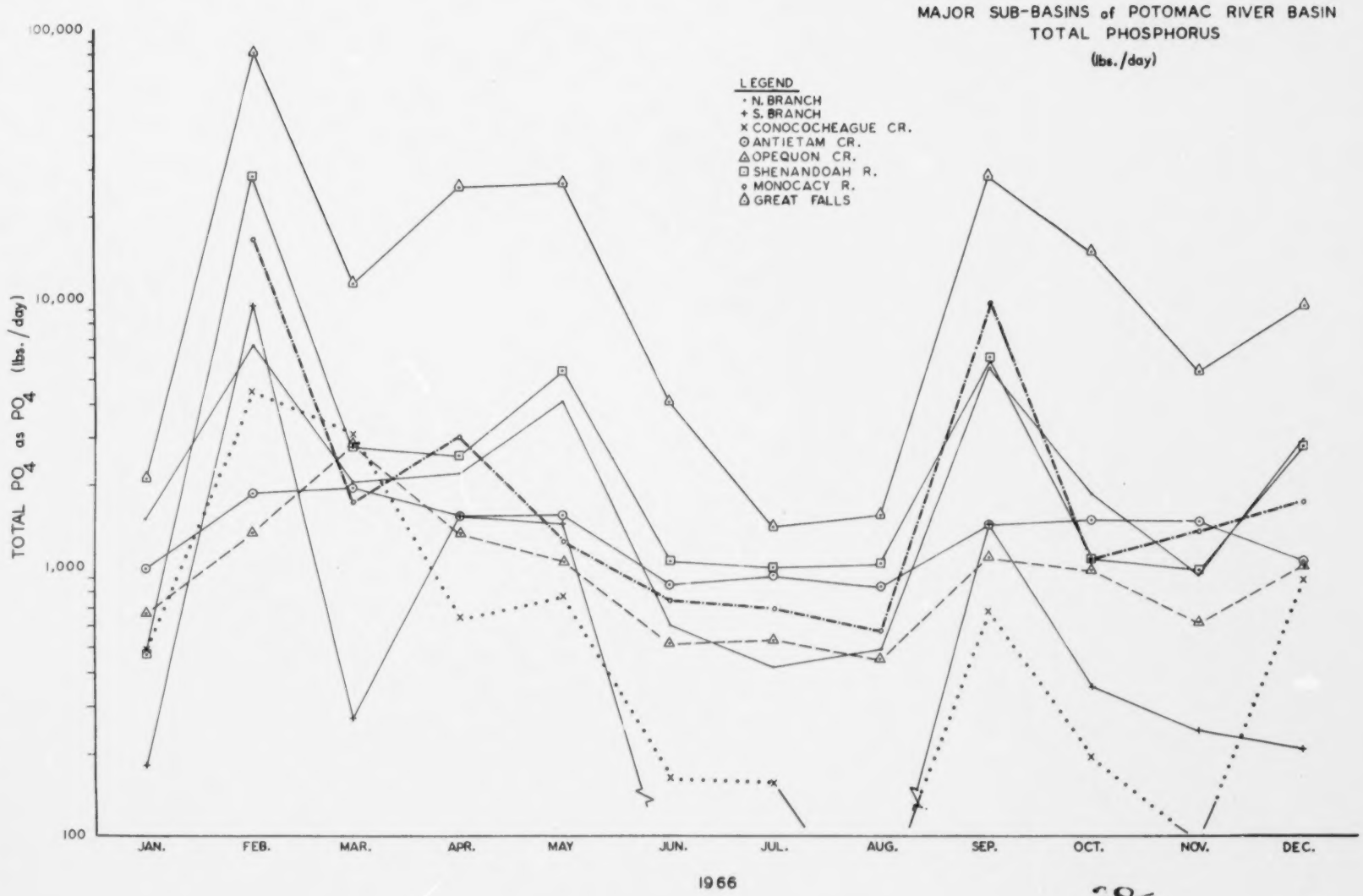

MAJOR SUB-BASINS of POTOMAC RIVER BASIN
TOTAL PHOSPHORUS
(lbs./day)
LEGEND
· N. BRANCH
+ S. BRANCH
× CONOCOCHEAGUE CR.
⊙ ANTIETAM CR.
△ OPEQUON CR.
□ SHENANDOAH R.
◦ MONOCACY R.
△ GREAT FALLS
TOTAL PO_4 as PO_4 (lbs./day)
100,000
10,000
1,000
100
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1966

Figure VII-3

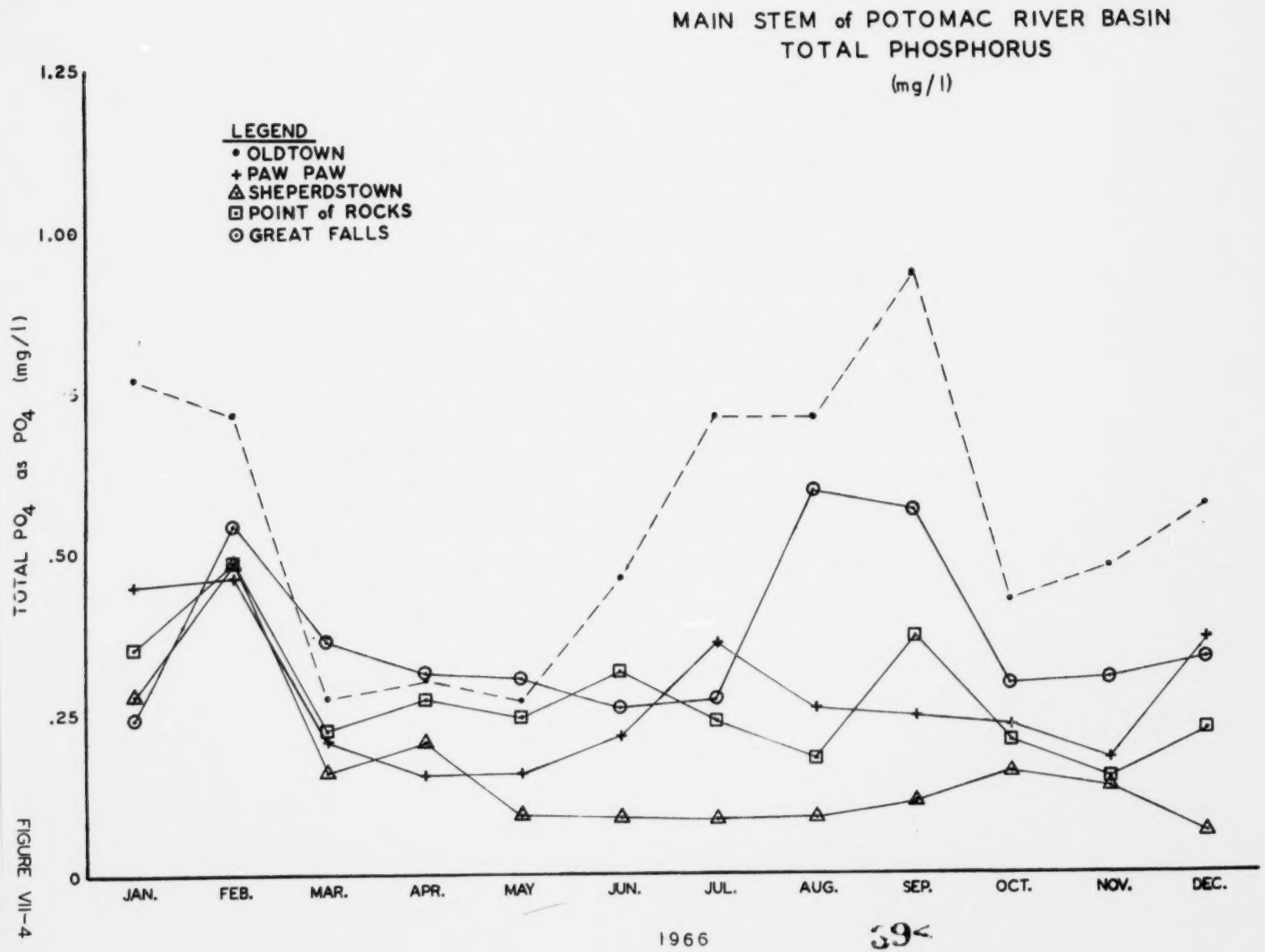

MAIN STEM of POTOMAC RIVER BASIN
TOTAL PHOSPHORUS
(mg/l)
LEGEND
• OLDTOWN
+ PAW PAW
△ SHEPERDSTOWN
⊡ POINT of ROCKS
⊙ GREAT FALLS
TOTAL PO4 as PO4 (mg/l)
1.25
1.00
.50
.25
0
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1966

FIGURE VII-4

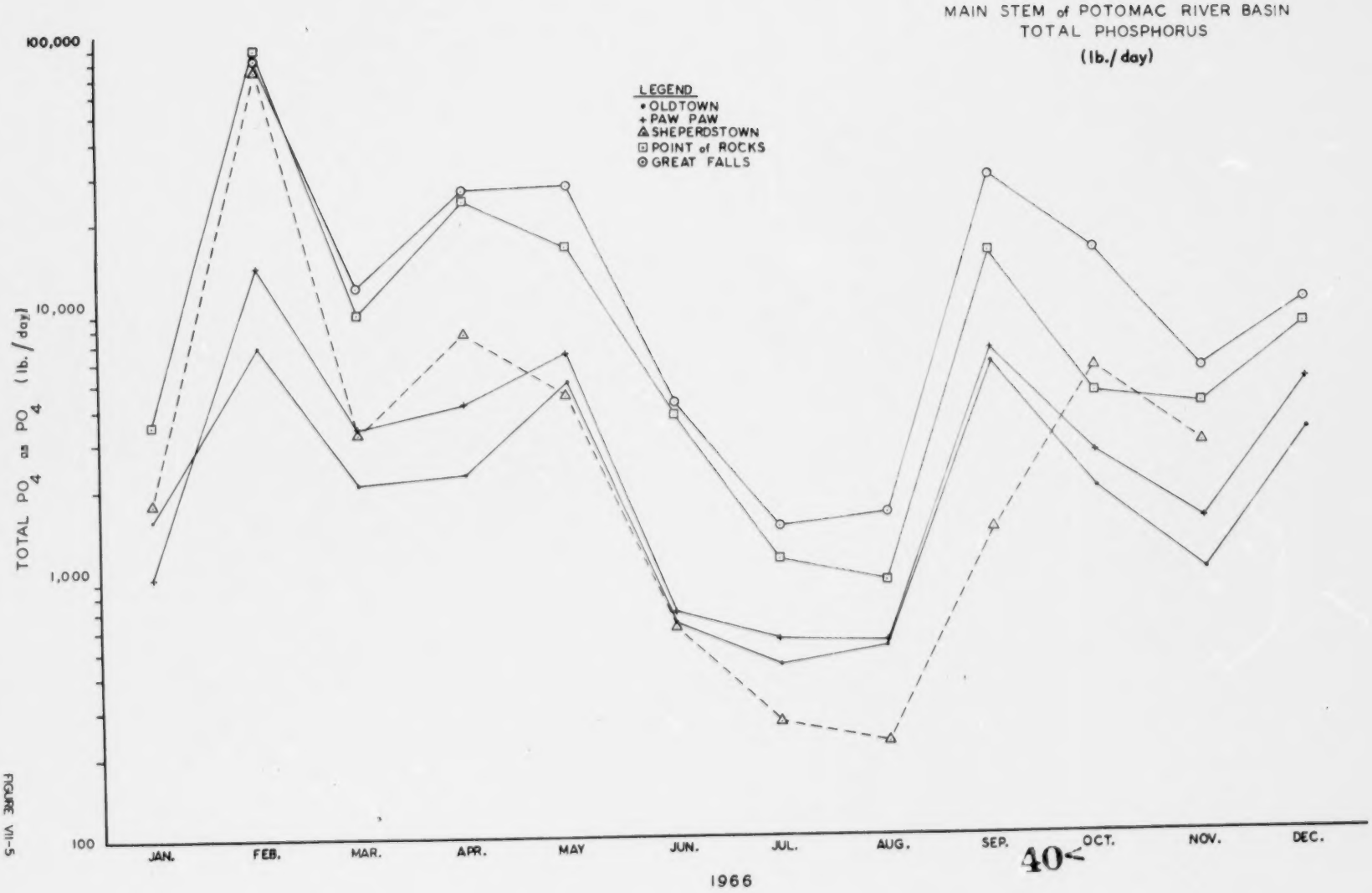

MAIN STEM of POTOMAC RIVER BASIN
TOTAL PHOSPHORUS
(lb./day)
LEGEND
• OLDTOWN
+ PAW PAW
△ SHEPERDSTOWN
□ POINT of ROCKS
⊙ GREAT FALLS
100,000
10,000
1,000
100
TOTAL PO4 as PO4 (lb./day)
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1966

FIGURE VII-5

Table VII-2

COMPARISON OF PHOSPHORUS CONCENTRATIONS AND LOADINGS
ALONG THE MAIN STEM OF THE POTOMAC

Station	River Mile	Total PO_4 as PO_4		
		(mg/l)	(lbs/day)	(lbs/day/sq.mi.)
Oldtown, Md.	287.30	.532	2,551	1.92
Paw Paw, W. Va.	276.55	.288	4,299	1.38
Hancock, Md.	238.60	.188	6,683	1.64
Hagerstown, Md.	210.20	.126	3,971	0.80
Shepherdstown, W. Va.	183.60	.199	15,073	2.54
Point of Rocks, Md.	159.50	.263	14,816	1.54
Great Falls, Md.	127.20	.379	17,013	1.48

3. Tributaries of the Lower Basin near Washington (Cabin John Creek, Seneca Creek, Goose Creek, Rock Creek, Anacostia River, and Occoquan Creek)

Figure VII-6 indicates average monthly phosphorus concentrations of 1.5 mg/l and greater in the Goose Creek, Cabin John Creek, and Anacostia River watersheds in 1966. The high concentrations in Goose Creek are attributed partly to wastewater discharges, while the somewhat lower levels in Cabin John Creek and Anacostia River are probably due to disruptions in the sanitary sewer systems. The average annual concentration of total phosphorus in the three other tributaries of the lower basin was less than 0.4 mg/l.

As presented in Table VII-3, the yield of phosphorus for Seneca and Cabin John creeks was 6.14 and 8.7 lbs/day/sq. mile, respectively.

Table VII-2

COMPARISON OF PHOSPHORUS CONCENTRATIONS AND LOADINGS
ALONG THE MAIN STEM OF THE POTOMAC

Station	River Mile	T. PO_4 as PO_4		
		(mg/l)	(lbs/day)	(lbs/day/sq.mi.)
Oldtown, Md.	287.30	.532	2,551	1.92
Paw Paw, W. Va.	276.55	.288	4,299	1.38
Hancock, Md.	238.60	.188	6,683	1.64
Hagerstown, Md.	210.20	.126	3,971	.80
Shepherdstown, W. Va.	183.60	.199	15,073	2.54
Point of Rocks, Md.	159.50	.263	14,816	1.54
Great Falls, Md.	127.20	.379	17,013	1.48

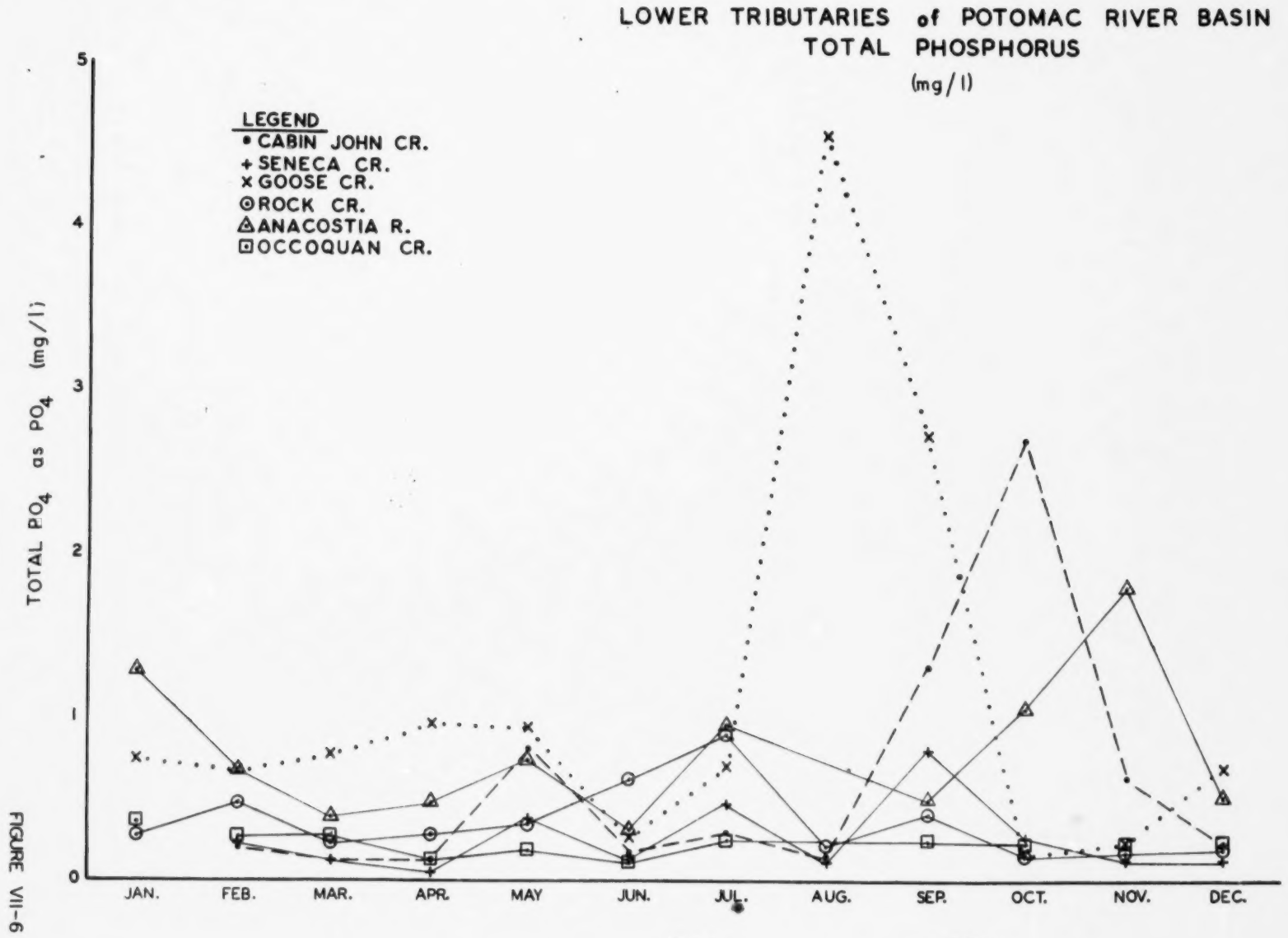

LOWER TRIBUTARIES of POTOMAC RIVER BASIN
TOTAL PHOSPHORUS
(mg/l)
LEGEND
• CABIN JOHN CR.
+ SENECA CR.
× GOOSE CR.
⊙ ROCK CR.
△ ANACOSTIA R.
⊡ OCCOQUAN CR.
TOTAL PO_4 as PO_4 (mg/l)
0
1
2
3
4
5
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1966

FIGURE VII-6

These yields are about fourfold greater than the 1.48 lbs/day/sq. mile yield found in the Potomac River at Great Falls, Maryland.

Table VII-3

COMPARISON OF PHOSPHORUS CONCENTRATIONS AND LOADINGS FOR TRIBUTARIES OF THE LOWER BASIN NEAR WASHINGTON

Station	Total PO_4 as PO_4		
	(mg/l)	(lbs/day)	(lbs/day/sq. mile)
Cabin John Creek (Cabin John, Md.)	0.662	210	8.75
Seneca Creek (Seneca, Md.)	0.290	774	6.14
Goose Creek (Leesburg, Va.)	1.010	791	2.34
Rock Creek (M St. Bridge, D.C.)	0.316	116	1.50
Anacostia River (Bladensburg, Md.)	0.753	231	1.78
Occoquan Creek (Occoquan, Va.)	0.225	1,246	2.31

B. INORGANIC AND TOTAL KJELDAHL NITROGEN

1. Major Sub-basins of the Upper Potomac

The inorganic nitrogen concentrations in the seven larger sub-basins, as shown in Figure VII-7, had a significant seasonal pattern (see Figure VII-2 for 1966 river discharges). In general, the inorganic nitrogen concentrations are directly related to the stream flow. This is at

Table VII-3

COMPARISON OF PHOSPHORUS CONCENTRATIONS AND LOADINGS FOR TRIBUTARIES OF THE LOWER REGION NEAR WASHINGTON, D. C.

Station	T. PO_4 as PO_4 (mg/l)	(lbs/day)	(lbs/day/sq. mi.)
Cabin John Creek (Cabin John, Md.)	.662	210	8.75
Seneca Creek (Seneca, Md.)	.290	774	6.14
Goose Creek (Leesburg, Va.)	1.010	791	2.34
Rock Creek . (M St. Bridge, D.C.)	.316	116	1.50
Anacostia River (Bladensburg, Md.)	.753	231	1.78
Occoquan Creek (Occoquan, Va.)	.225	1,246	2.31

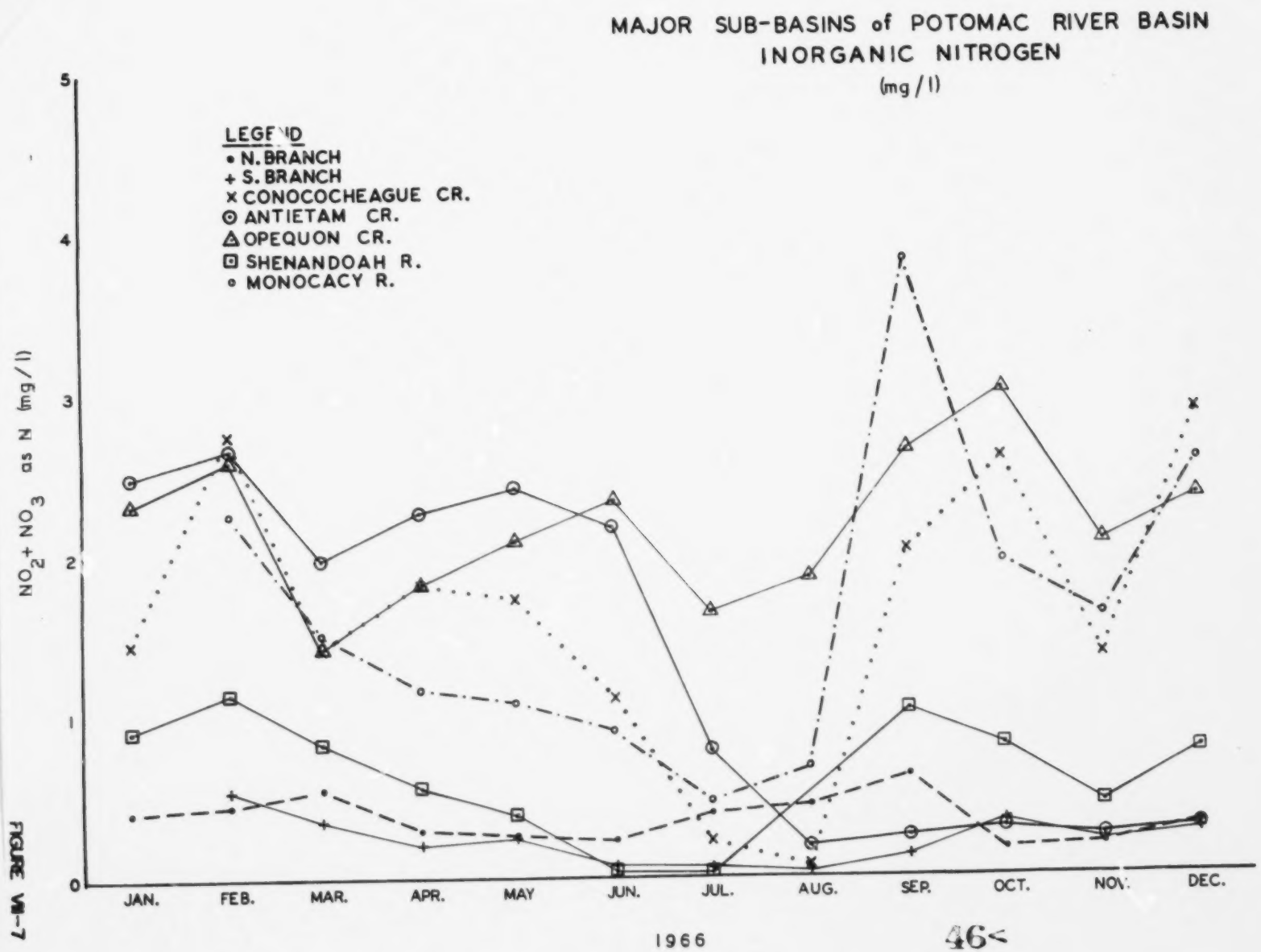

MAJOR SUB-BASINS of POTOMAC RIVER BASIN
INORGANIC NITROGEN
(mg/l)
LEGEND
• N. BRANCH
+ S. BRANCH
× CONOCOCHEAGUE CR.
⊙ ANTIETAM CR.
△ OPEQUON CR.
⊡ SHENANDOAH R.
◦ MONOCACY R.
$NO_2 + NO_3$ as N (mg/l)
0
1
2
3
4
5
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1966

FIGURE VM-7

variance with total phosphorus concentrations which are inversely related to flow.

During the high flow months, February through May, as much as 100,000 lbs/day of inorganic nitrogen entered the Potomac (Figure VII-8). During the low flow months of June, July, and August, the inorganic nitrogen loadings were less than 400 lbs/day for the major sub-basins.

The Conococheague and Monocacy sub-basins had a yield of over 10 lbs/day/sq. mile. This is over twofold larger than the remaining five watersheds (see Table VII-4).

The analysis for TKN was initiated in midsummer 1966. Therefore loadings for the entire year were not calculated.

2. Main Stem

As shown in Figure VII-9, the concentration of inorganic nitrogen on the main stem varied directly with flow. This seasonal pattern was also observed at the sub-basin stations.

It can be seen in Table VII-5 that the average annual concentrations of inorganic nitrogen were higher for the three stations in the lower part of the basin. The Conococheague, Antietam, and Monocacy sub-basin inputs were apparently responsible for these higher nitrogen levels.

The inorganic nitrogen loadings shown in Figure VII-10 demonstrate the direct relationship between flow and concentration. The loadings in the high flow month of September were about 100-fold larger than during the summer low flow months.

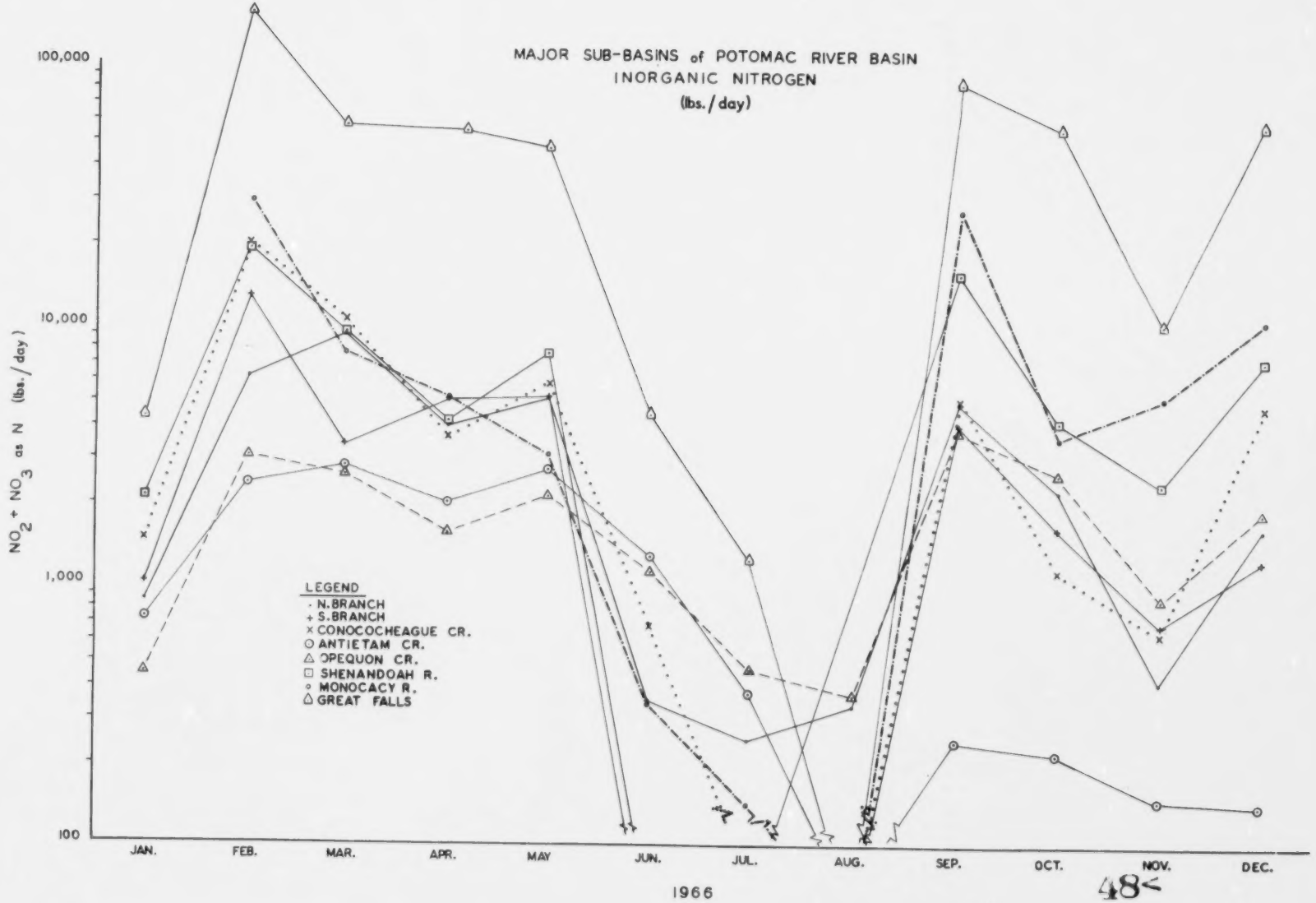


Figure VII-8

VII-14

Table VII-4

COMPARISON OF NITROGEN CONCENTRATIONS AND LOADINGS FOR THE MAJOR SUB-BASINS

Sub-Basin (Station)	$NO_2 + NO_3$ as N (mg/l)	$NO_2 + NO_3$ as N (lbs/day)	$NO_2 + NO_3$ as N (lbs/day/sq.mi.)	TKN as N (mg/l)
North Branch (Oldtown, Md.)	.378	3,267	2.46	.784
South Branch (Romney, W. Va.)	.296	3,655	2.52	-
Conococheague Creek (Williamsport, Md.)	1.593	5,317	11.46	.019
Antietam Creek (Antietam, Md.)	1.429	1,321	4.67	.536
Opequon Creek (Martinsburg, W. Va.)	2.149	1,817	5.88	.264
Shenandoan River (Bloomery, W. Va.)	.654	6,714	2.33	.580
Monocacy River (Frederick, Md.)	1.744	8,661	10.65	.693
Potomac River (Great Falls, Md.)	.903	49,009	4.29	.270

MAIN STEM of POTOMAC RIVER BASIN
INORGANIC NITROGEN
(mg/l)

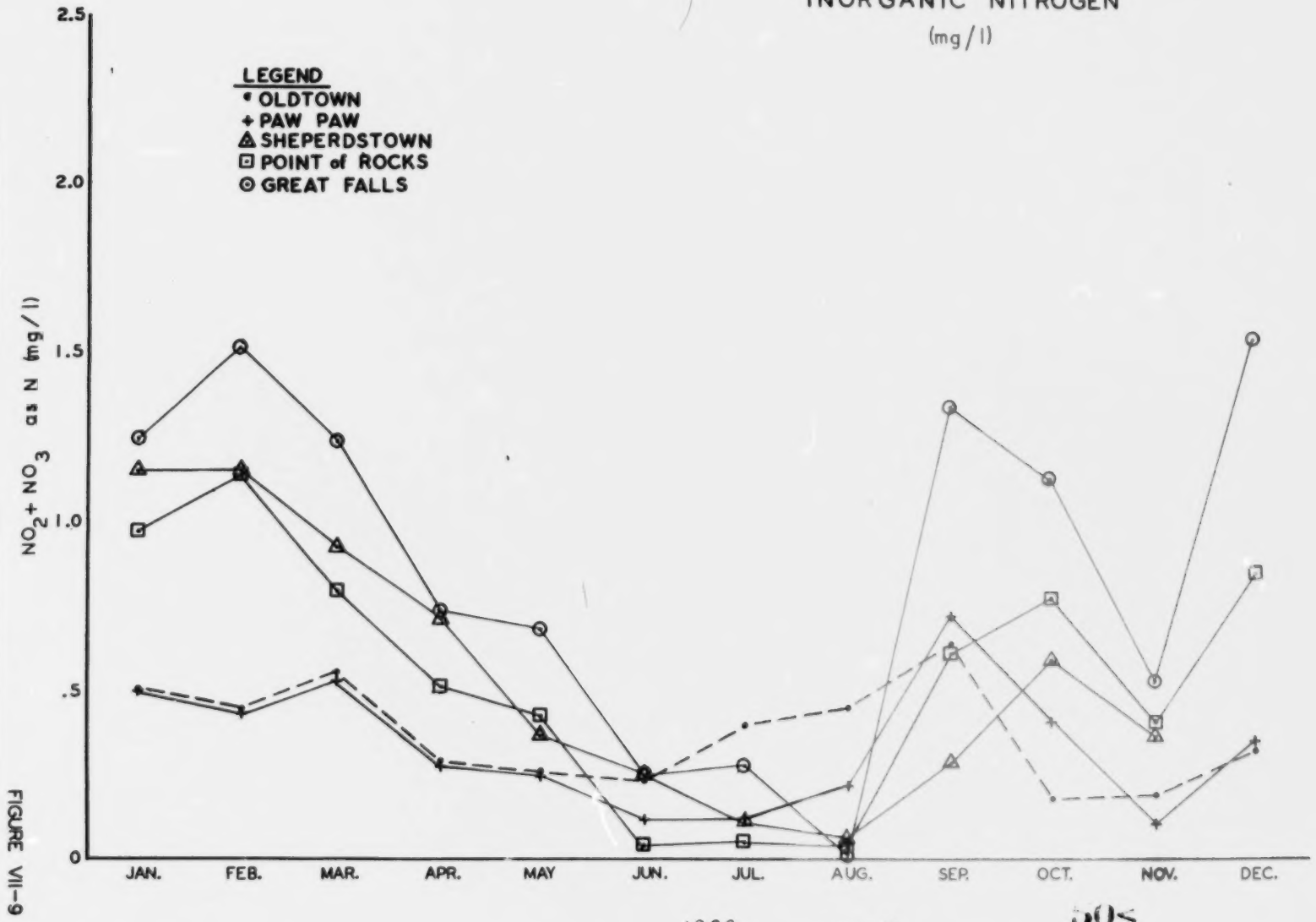


FIGURE VII-6

1966

50

Table VII-5

COMPARISON OF NITROGEN CONCENTRATIONS AND LOADINGS FOR THE MAIN STEM

Station	$NO_2 + NO_3$ as N			
	(mg/l)	(lbs/day)	(lbs/day/sq.mi.)	(mg/l)
Oldtown, Md.	.378	3,267	2.46	.784
Paw Paw. W. Va.	.324	7,791	2.51	.432
Hancock, Md.	.294	10,271	2.50	.298
Hagerstown, Md.	.279	8,853	1.78	.386
Shepherdstown, W. Va.	.639	27,205	4.58	.378
Point of Rocks, Md.	.581	26,959	2.79	.422
Great Falls, Md.	.923	49,209	4.29	.270

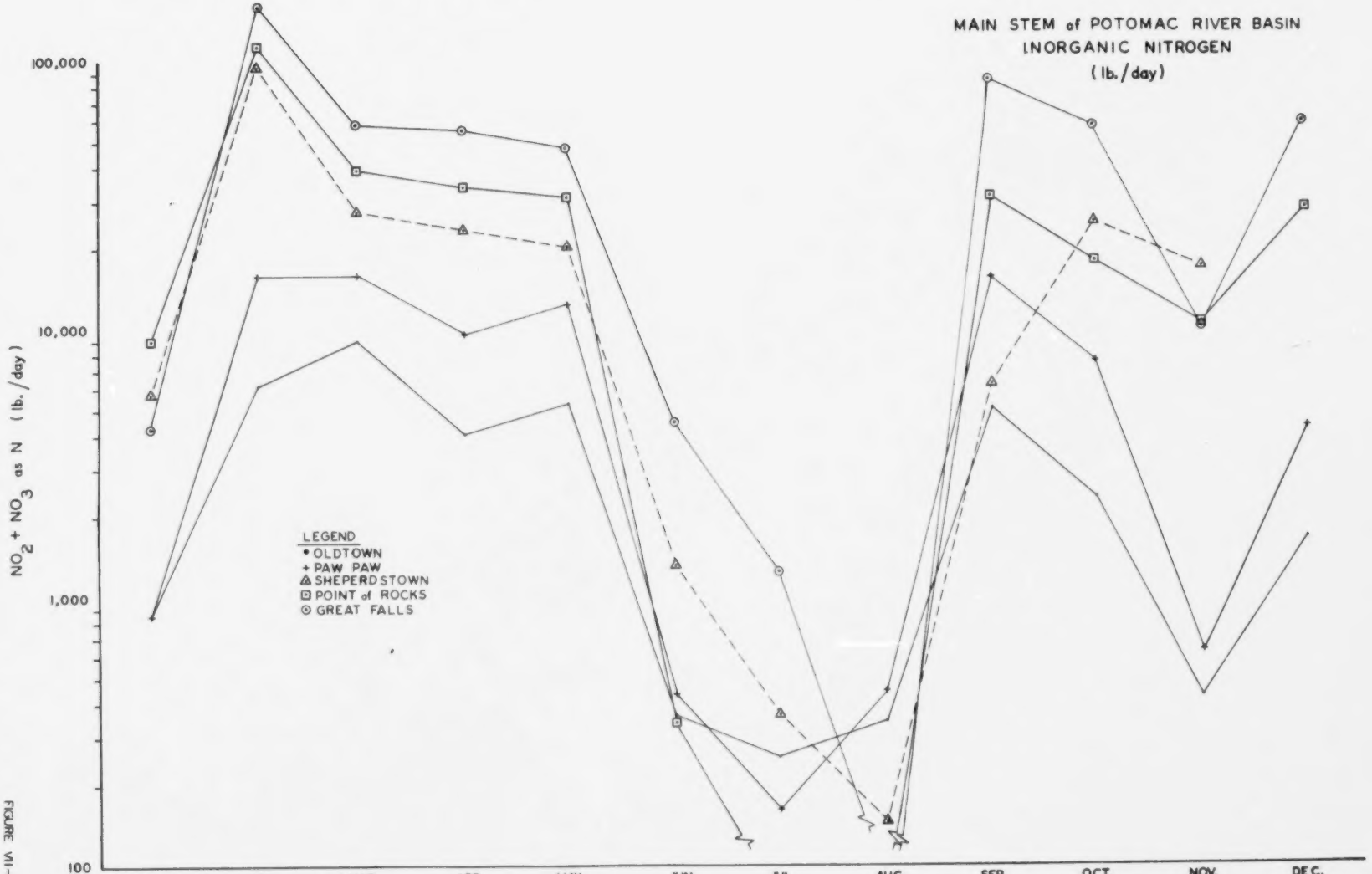


FIGURE VII-O

1966

On an annual basis, TKN concentrations in the main stem were about 0.30 to 0.45 mg/l with the exception of Oldtown, Maryland, which had an average TKN of 0.78 mg/l. The high concentration at Oldtown was probably the result of the large domestic and industrial discharges into the North Branch.

3. Tributaries of the Lower Basin near Washington

The annual average inorganic nitrogen concentrations in the tributaries near Washington varied from 0.48 to 1.31 mg/l with the highest level in the Seneca, Rock Creek, and Anacostia watersheds. Figure VII-11 shows that seasonal concentrations varied widely among the sub-basins. For example, inorganic nitrogen was higher in summer months and lower in winter months for Seneca Creek while showing the opposite pattern in Goose Creek.

On a yield basis, Goose and Seneca Creek sub-basins had contributions of 7.7 and 38.5 lbs/day/sq. mile. The remaining sub-basins had yields of 3.0 to 4.0. (See Table VII-6.)

The TKN concentrations for the six select sub-basins ranged from 0.349 to 1.130 mg/l with higher levels in Cabin John and Anacostia watersheds.

C. MASS BALANCE OF PHOSPHORUS

The phosphorus loading at any given sampling point in the basin is dependent upon many variables such as flow, soil condition, and land usage. On an annual basis, the amount of phosphorus can be expressed mathematically as follows:

$$P_t = P_w + P_l + P_o \pm P_s$$

LOWER TRIBUTARIES of POTOMAC RIVER BASIN
INORGANIC NITROGEN
(mg/l)

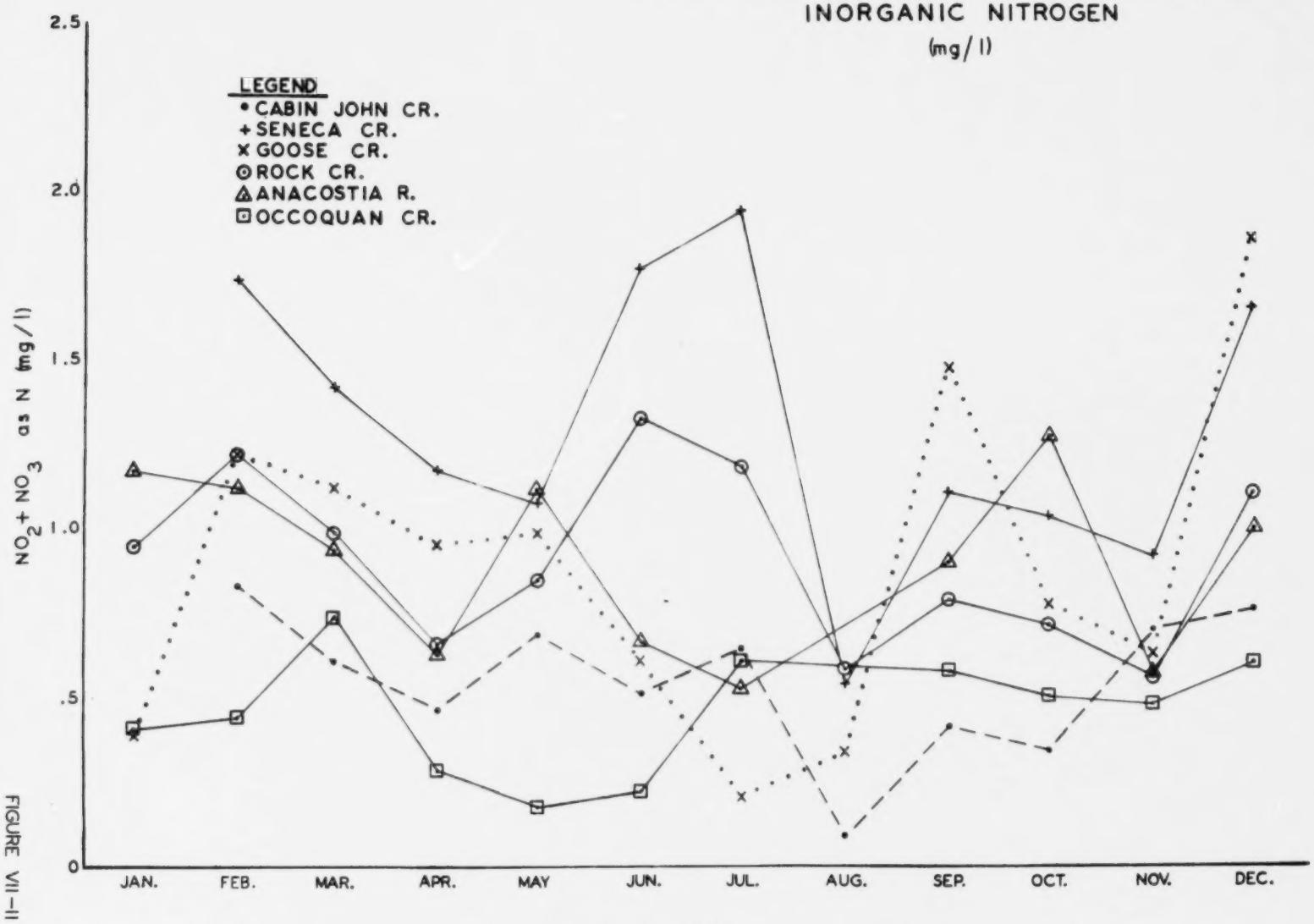


FIGURE VII-11

1966

VII - 20

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Table VII-6

COMPARISON OF NITROGEN CONCENTRATIONS AND LOADINGS FOR TRIBUTARIES OF THE LOWER REGION NEAR WASHINGTON, D.C.

Station	$NO_2 - NO_3$ as N			TKN as N
	(mg/l)	(lbs/day)	(lbs/day/sq.mi.)	(lbs/day/sq.mi.)
Cabin John Creek (Cabin John, Md.)	.565	89	3.71	.796
Seneca Creek (Seneca, Md.)	1.309	974	7.73	.409
Goose Creek (Leesburg, Va.)	.924	1,308	38.49	.417
Rock Creek (M St. Bridge, D.C.)	.885	274	3.56	.349
Anacostia River (Bladensburg, Md.)	.942	409	3.15	1.130
Occoquan Creek (Occoquan, Va.)	.478	2,253	4.17	.512

where:

P_t = phosphorus observed at Point t

P_w = phosphorus in wastewater discharge above Point t

P_l = phosphorus coming from land above Point t

P_o = phosphorus from other sources above Point t

P_s = phosphorus lost or released from storage in the stream bed

Utilizing the 1966 data and rearranging the above formulation, the amount of phosphorus loadings deposited or released from storage in the stream bed were determined as shown in Table VII-7.

The negative signs on the phosphorus loading storage values indicate that at six of the eight stations phosphorus was retained in the stream channel, bound there by sediments and aquatic plants. Although no core data are available for the upper Potomac, data from the estuary indicate that there is a more than fivefold increase in phosphorus in the sediments near wastewater discharge points. This apparent loss of phosphorus to sediments may be temporary in that during flood conditions a considerable tonnage of sediment is transported into the estuary in a matter of days.

Table VII-7

PHOSPHORUS BALANCE

Station	Area (sq. mi.)	Measure (lbs/day)	P_w From Wastewaters (lbs/day)	P_l Land yield (lbs/day/sq.mi.)	lbs/day	($P_w + P_l$) Total from Wastewater and Land (lbs/day)	(P_s)* Difference (Measure-total) (lbs/day)
North Branch	1,328	2,551	4,850	0.50	664	5,518	-2,964
South Branch	1,450	1,535	460	0.6	725	1,185	+ 350
Conococheague	469	1,226	920	1.0	470	1,390	- 160
Antietam	283	1,353	2,100	1.0	285	2,385	-1,032
Opequan	309	1,109	1,100	1.0	310	1,410	- 301
Shenandoah	3,012	5,105	6,210	0.8	2,400	9,610	-3,505
Monocacy	813	3,385	1,800	1.0	815	2,615	+ 770
Potomac at Great Falls	11,460	17,013	18,430	0.78	8,610	27,040	-10,027

* In the formulation P_o is assumed to be zero

CHAPTER VIII

SEDIMENTS

A. EFFECTS ON NUTRIENT CONCENTRATIONS

The effect of sediments on the concentrations of nutrients in the surface water are summarized below:

1. Sediments contain nutrients. On the average, topsoil particles contain 200 mg/l of adsorbed phosphorus [3].
2. Sediments can act as transport mechanisms. Studies by Wadleigh [3] indicate that when phosphorus reaches the stream its primary vector is soil particles.
3. Due to the adsorption phenomenon, sediments when deposited in the stream channel also trap nutrients.
4. More than 99 percent of the soluble nitrogen in the soil is the nitrate form [4].
5. The forms of nitrogen present greatly affect the leachability of the material. Nitrates leach at a more rapid rate than the other forms of nitrogen [4].
6. In contrast to the high mobility of nitrate nitrogen, phosphorus compounds react vigorously with soil and have a very low mobility [4].

Sediments in water may also reduce the penetration of light and thus reduce photosynthesis by algal cells. This reduction will in turn lessen the effect of the algal cells on dissolved oxygen concentrations in the surface waters.

B. SPATIAL AND TEMPORAL VARIATIONS

A study of the sediment sources and transport was prepared by Wark and Keller [7] in 1963 for the Interstate Commission on the Potomac River Basin. Their study indicated the following:

1. The average sediment discharge of the streams in the Potomac River Basin varied from 42 to 4,600 kilopounds (kips) per square mile. The wide variation was mainly due to land use.
2. During the sampling period of the study, the estimated annual sediment discharge of the Potomac River Basin was 340 kips per square mile or a total of 5 million kips.
3. For two streams on which daily measurements were made, about 90 percent of the annual load was discharged 10 percent of the time.

In comparing the sediment loading at Point of Rocks with those of 12 other major rivers in the USA in 1963, it ranked seventh.

An analysis was made of more recent sediment data to determine further the effects of sediments on nutrient levels. The sediment data for five sampling stations during 1966 are given in Table VIII-1. During 1966, the annual sediment yield varied from a minimum of 98 kips/sq. mile at Point of Rocks to 400 kips/sq. mile in the North Branch at Cumberland. For all five stations the maximum sediment load occurred in February with a range of 34 to 57 percent of the annual loading.

Table VIII-1

SUMMARY OF SEDIMENT SAMPLING DATA

POTOMAC RIVER BASIN 1966

Station	Total for Year (kips)	Daily Average (kips/day)	Max. Month	% of Annual for Max. Month	Annual Yield (kips/sq.mi.)
Potomac River (Point of Rocks, Md.)	940,000	2,600	February	55	98
Monocacy River (Jug Bridge, Md.)	236,000	645	February	34	290
Conococheague Creek* (Fairview, Md.)	200,000	275	February	44	200
N. Br. Potomac River (Cumberland, Md.)	353,700	970	February	57	400
N.W. Br. Anacostia River (Colesville, Md.)	27,400	75	February	32	130

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For 1966, the sediment loading to the entire Potomac River Basin has been estimated in Table VIII-2.

Table VIII-2

1966 SEDIMENT LOADING
POTOMAC RIVER BASIN

Area	Yield (kips/sq.mi.)	Drainage Area (sq.mi.)	Annual Loading (kips)	Percent of Total
Upper Potomac Above Point of Rocks	98	9,651	940,000	50
Potomac Below Point of Rocks and Above Estuary	290*	1,909	553,000	29
Potomac Estuary	130**	3,110	404,000	21
Total Basin	129	14,670	1,897,000	100

* Yield for Monocacy River Basin
** Yield for Anacostia River Basin

When compared to the estimate of Wark and Keller [7], the annual yield for 1966 was about 38 percent of the loading for their sampling period in 1961-1962.

C. SEDIMENT LOADINGS INTO THE ESTUARY

Data summarized in Table VIII-3 show that sediment loadings above Great Falls may be decreasing. The average flow for this eight-year period also decreased. In 1961, the annual loading was the largest

Table VIII-2

1966 SEDIMENT LOADING

POTOMAC RIVER BASIN

Area	Yield (kips/sq.mi.)	Drainage Area (sq. mi.)	Annual Loading (kips)	% of Total
Upper Potomac above Point of Rocks	98	9,651	940,000	50
Potomac below Point of Rocks and above Estuary	290*	1,909	553,000	29
Potomac Estuary	130**	3,110	404,000	21
Total	129	14,670	1,897,000	100

* Yield for Monocacy River Basin

** Yield for Anacostia River Basin

(2.5 million kips) as compared to the lowest (1.2 million kips) in 1966. (See Appendix A for monthly loadings at Great Falls, Maryland.)

Table VIII-3 also shows that on an annual yield basis the average sediment yield for the period 1961-1966 was 184 kips/sq. mile with a minimum and a maximum of 112 and 240 kips/sq. mile, respectively. The highest percentage of annual contributions occurred during either February or March with values ranging from 51 to 90 percent of annual loadings.

Table VIII-3

SEDIMENT DATA*

POTOMAC RIVER BASIN

BELOW CONFLUENCE OF MONOCACY RIVER

Year	Total for Year (kips)	Daily Average (kips/day)	Maximum Month	% of Annual for Maximum Month	Annual Yield (kips/sq.mi.)
1961	2,515,500	6,890	February	65.7	240
1962	1,996,600	5,470	March	64.2	190
1963	2,378,700	6,520	March	89.8	227
1964	2,052,000	5,600	March	41.6	196
1965	1,503,600	4,100	March	54.3	143
1966	1,175,000	3,200	February	50.8	112
Average	1,937,000	5,300	-	-	184

* Sediment data based on a summation of Potomac River at Point of Rocks and Monocacy River at Jug Bridge. Total drainage above the sampling station is equal to 10,468 square miles. Drainage area at Great Falls, Maryland is 11,640 square miles.

CHAPTER IX

TEMPORAL AND SPATIAL DISTRIBUTION OF NUTRIENTS ENTERING THE POTOMAC ESTUARY

A. HISTORICAL TRENDS

The only existing long-term (more than 10 years) nutrient data for the Potomac River Basin are nitrogen data collected at Great Falls. Sediment measurements at Point of Rocks and Monocacy have been available since 1961. Mean monthly flow, nutrient, and sediment data for the Potomac River above Great Falls are presented in Appendix A.

The nitrate-nitrogen loadings for the years 1949-1967 show a definite seasonal pattern (Figure IX-1). The seasonal variation closely parallels that of river discharge. Except for 1967, there appears to be a slight downward trend in nitrates, especially during low flow months. On an average annual basis for 1960-1967 (Table IX-1) the data also indicate a direct relationship between nutrient loadings and river discharge.

B. TEMPORAL VARIATIONS

An important aspect of the nutrient control problem is the annual variation in nutrient contributions by the various sources. The amount of phosphorus and nitrogen variation for the Potomac main stem station at Great Falls can be seen in Figure IX-2. During the summer months, less than 1,000 lbs/day of phosphorus entered the estuary even though more than 18,400 lbs/day are discharged to the surface waters in the upper basin from wastewater treatment plants.

POTOMAC RIVER BASIN

NITRATE NITROGEN LOADINGS

at

GREAT FALLS, Md.

1949-1967

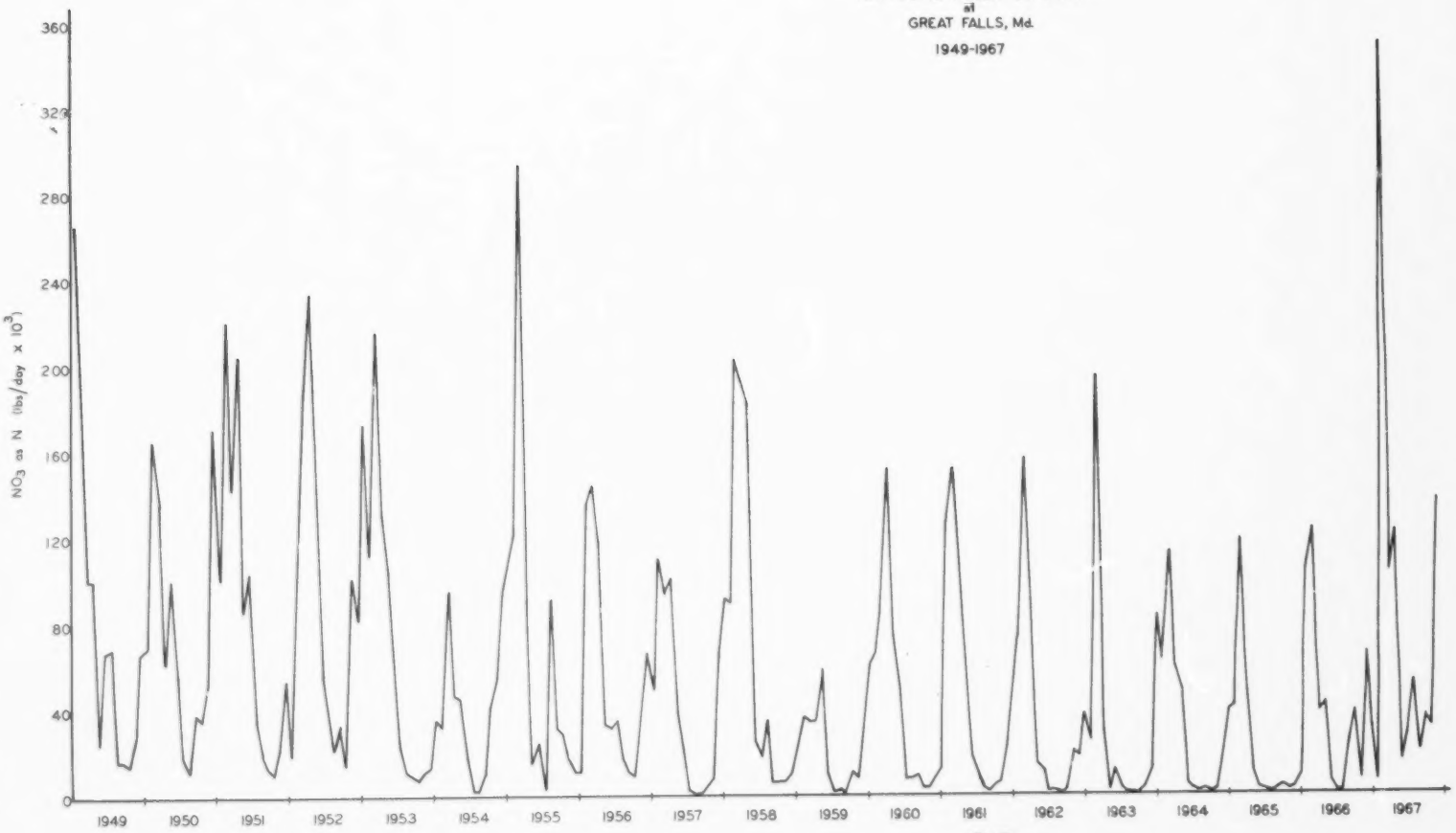

FIGURE IX - 1

Table IX-2

1960 - 1967 SUMMARY OF DATA
POTOMAC RIVER
AT
GREAT FALLS, MD.

Item	1960	1961	1962	1963	1964	1965	1966	1967
Flow (cfs)	10,886	10,184	10,579	7,854	9,307	8,119	6,700	10,800
Temp. (Deg. °F)	59	59	59	60	59	61	61	60
T. Solids (mg/l)	147	159	165	181	196	200	191	159
NO_2 (mg/l)	.014	.010	.015	.013	.008	.006	.013	.018
(#/day)	580	740	525	561	487	584	549	565
NO_3 (mg/l)	.600	.490	.480	.380	.490	.570	.821	1.470
(#/day)	42,000	43,800	36,200	26,700	25,000	26,600	38,000	76,900
NO_2+NO_3 as N (mg/l)	-	-	-	-	-	-	.233	-
(#/day)	-	-	-	-	-	-	46,700	-
TKN as N (mg/l)	-	-	-	-	-	-	.300	-
(#/day)	-	-	-	-	-	-	18,000	-
T. PO_4 as PO_4 (mg/day)	-	-	-	-	-	-	.330	-
(#/day)	-	-	-	-	-	-	17,000	-

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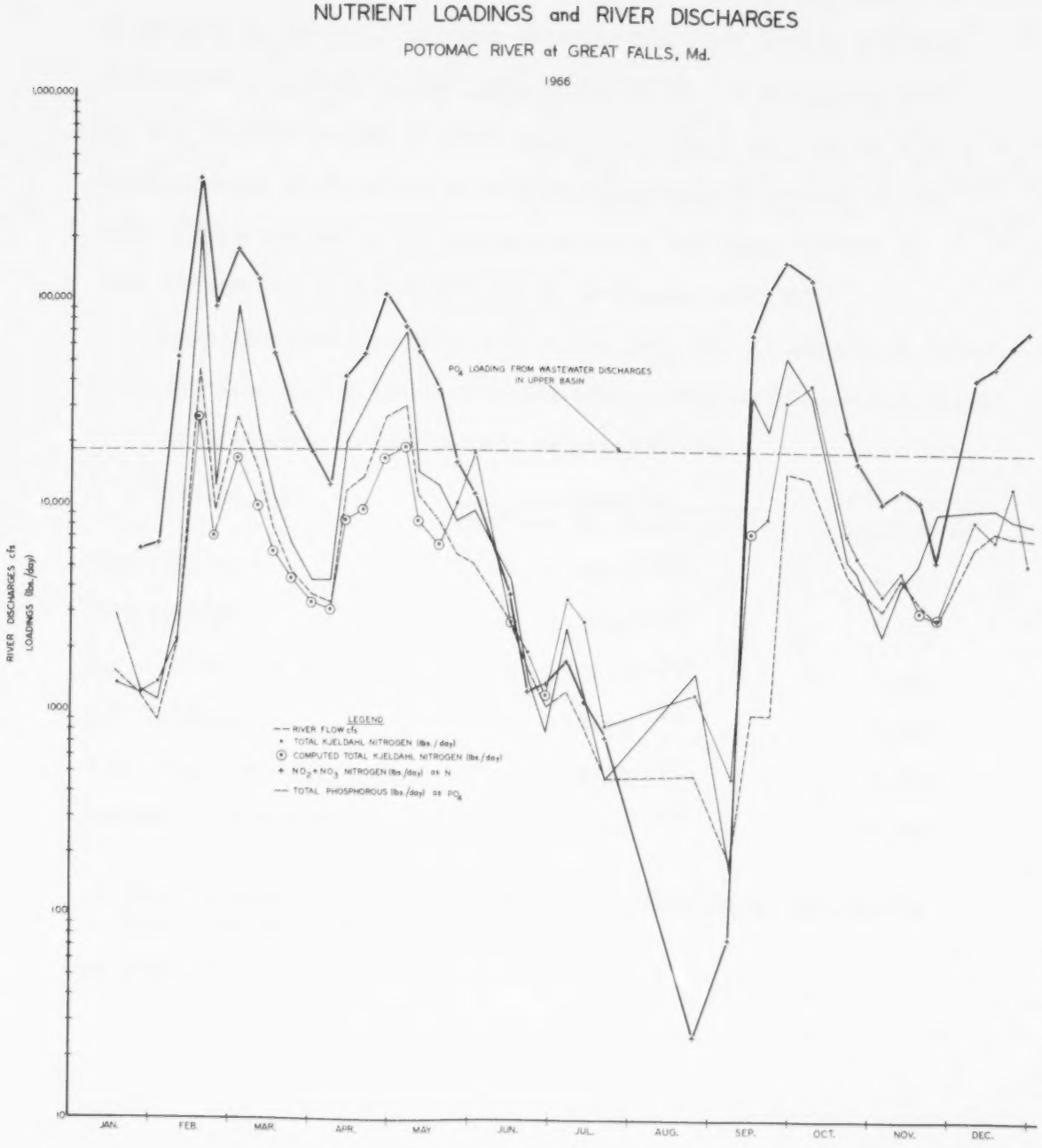

IX-4

Figure IX-2

The current nutrient loadings into the upper Potomac Estuary from wastewater discharges in the Washington area are about 63,000 lbs/day of total phosphorus as PO_4 and 54,000 lbs/day of TKN. On an annual average basis, over 87 percent of the phosphorus and 53 percent of the total nitrogen entering the upper estuary are from wastewater discharges in the upper basin and in the Washington area. For the low flow months of July, August, and September, during which eutrophication problems are most pronounced, over 90 percent of the total phosphorus and total nitrogen entering the upper estuary is from the wastewater discharges in the Washington area [1].

Regression analyses were made on the data for the station at Great Falls obtained during the period 1961-1967. Predictive equations based on river discharge were developed, as given below:

Parameter Unit		Equation (Q=river discharge in cfs)	Correlation Coefficient
NO_2* (lbs/day)	=	$0.0337Q^{1.058}$	0.865
NO_3* (lbs/day)	=	$0.0362Q^{1.475}$	0.903
$NO_2 + NO_3$** (lbs/day)	=	$0.0361Q^{1.546}$	0.924
TKN (lbs/day)	=	$0.0965Q^{0.892}$	0.927
Total PO_4 (lbs/day)	=	$0.2851Q^{1.179}$	0.964
Sediments (kips/day)	=	$0.995\ Q^{1.768}$	0.904

* Based on data from the U.S. Army Corps of Engineers, Dalecarlia Water Treatment Plant for 1961-1967.

** Based on CTSL data for 1966.

As can be seen in the above listings, the exponent of the NO_3 nitrogen and the NO_2 + NO_3 nitrogen is greater than 1.4. This confirms the studies of Bailey [4] in which he reports a positive relationship between nitrate movement and amount of water added to the test area. The exponent of the phosphorus relationship is near unity, indicating that the measure loading is more a dissolved transport phenomenon and not related to silt transport which has an exponent of 1.768. More data at high flows are needed to substantiate these observations.

Table IX-2 presents the predicted average monthly nutrient loadings based upon the average monthly flows from the upper basin of the Potomac River at Great Falls, Maryland. The largest variations in the loadings were in NO_2 + NO_3 nitrogen, which varied from 17,400 to 174,800 lbs/day.

These variations are more pronounced if daily values are considered. For example, in August of 1966, with a river discharge of about 500 cfs, less than 1,000 lbs/day of total phosphorus as PO_4 and NO_2 + NO_3 as N entered the upper estuary from the upper Potomac River Basin, while on February 14, 1966, with a flow greater than 40,000 cfs, about 217,000 and 354,000 lbs/day of PO_4 and NO_2 + NO_3 as N, respectively, entered the estuary.

The wide variation in the nutrient loadings in the Potomac River at Great Falls and other stream monitoring stations clearly demonstrates the need to sample various flows continuously over a long

Table IX-2

PREDICTED AVERAGE MONTHLY NUTRIENT LOADINGS*

POTOMAC RIVER

NEAR WASHINGTON, D. C.

Month	Flows** (cfs)	PO_4 as P (lbs/day)	TKN as N (lbs/day)	$NO_3 + NO_2$ as N (lbs/day)
Jan.	13,500	36,220	9,800	98,600
Feb.	16,630	32,151	11,410	101,000
Mar.	21,000	43,870	14,140	174,800
Apr.	20,000	42,210	13,530	161,000
May	14,150	28,090	10,340	97,400
June	8,588	15,420	6,780	44,270
July	5,454	8,900	4,610	21,600
Aug.	4,212	10,180	4,040	15,760
Sept.	4,340	7,560	4,100	17,400
Oct.	6,220	10,580	5,000	27,560
Nov.	6,700	11,170	5,280	28,800
Dec.	9,886	17,850	7,540	54,200
Average	11,129	21,180	8,175	72,830

* Based on regression studies

** Average Monthly flows adjusted for diversions.

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period of time before an identification of nutrient sources can be made. Moreover, as Figure IX-2 shows, sampling only under summer low flow conditions can lead to misleading conclusions as to the relative temporal and spatial distribution of nutrients.

C. SPATIAL DISTRIBUTION OF NUTRIENTS

Of the 11,460 square miles of drainage area, approximately 73 percent was represented by sampling in eight of the major sub-basins (Table IX-3). The annual yield of these sub-basins was 67.7 percent of the NO_2 + NO_3 nitrogen and 97.2 percent of the phosphorus totals measured at Great Falls.

The close agreement between the amount of phosphorus observed at Great Falls and that accounted for by the various sources is probably due to the following:

1. Most of the phosphorus was from wastewater discharges,
2. The sampling stations were selected to reflect the loadings from urban population centers, and
3. Other sources of phosphorus were minor.

At Great Falls, the fairly close agreement between the drainage area percentage of the total basin (73.0) and NO_2 + NO_3 percentage of the total basin nitrogen (67.7) reaffirms the conclusion that most of the nitrogen is from land runoff.

Table IX-3 shows that the Shenandoah and Monocacy River basins account for about 50 percent of the phosphorus and 34 percent of the NO_2 + NO_3 nitrogen recorded at Great Falls. When the South Branch

Table IX-3

SPATIAL DISTRIBUTION OF NUTRIENTS
UPPER POTOMAC RIVER BASIN
ABOVE GREAT FALLS, MD.

Station	Drainage Area		Average Annual Loading			
			NO_2+NO_3 as N		T. PO_4 as PO_4	
	(Sq. Mi.)	% of T. Basin	(#/day)	% of T. Basin	(#/day)	% of T. Basin
Potomac River at Great Falls, Md.	[illegible]	100.0	46,700	100.0	17,000	100.0
Monocacy River at Jay Bridge, Md.	[illegible]	7.1	8,660	18.5	3,400	20.0
Shenandoah River at Bloomery, W. Va.	3,013	26.0	6,720	14.4	5,100	30.0
Antietam Creek at Antietam, Md.	281	2.4	1,320	2.8	1,400	8.2
Opequan Creek at Martinsburg, W. Va.	309	2.7	1,820	3.9	1,100	6.5
Conocheague Creek at Williamsport, Md.	469	4.1	5,300	11.4	1,200	7.1
Cacapon River at Great Cacapon, W. Va.	677	5.9	890	1.9	220	1.3
S. Branch Potomac River near Romney, W. Va.	1,450	12.7	3,660	7.8	1,500	8.8
N. Branch Potomac River near Oldtown, Md.	1,328	11.6	3,270	7.0	2,600	15.3
Total of Sub-basins	8,339	73.0	31,660	67.7	16,520	97.2

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and the North Branch of the Potomac River are compared, it can be seen that the nitrite + nitrate contributions of the two, which have about the same drainage area, are approximately the same. However, in the North Branch the phosphorus loading is 60 percent greater than in the South Branch, due primarily to a greater volume of industrial and municipal wastewater discharges. Based upon the estimates for land runoff and wastewater contributions in Chapter VI, an estimate of total nutrient loadings was made (Table IX-4). Also presented in the table are the measured loadings at Great Falls.

Of the 27,040 lbs/day of phosphorus entering the surface waters, about 68 percent is from wastewater discharges with the remaining 32 percent from land runoff and other sources. Based upon the mass balance equation presented in Chapter VII, about 10,000 lbs/day or 37 percent of the 27,040 lbs/day were deposited on the stream bed, mostly in the Shenandoah and North Branch watersheds.

In 1966, about 79 percent of the 54,625 lbs/day of total nitrogen that entered the surface waters was from land runoff with other sources of wastewater contributing the remaining 21 percent. Most of the total nitrogen from land and other sources was in the nitrate form with TKN being the predominant form in municipal and industrial discharges. About 90 percent of the total nitrogen measured in the Potomac River at Great Falls can be attributed to either wastewater or land runoff sources.

Table IX-4

ESTIMATED UPPER POTOMAC BASIN NUTRIENT LOADING 1966

Source	T. PO_4 as PO_4 (lbs/day)	% of total	NO_2 + NO_3 as N (lbs/day)	% of total	TKN as N (lbs/day)	% of total	Total Nitrogen	% of total
Wastewater	18,430	68	*	0	10,680	66	10,680	21
Land Runoff	8,610	32	38,500	100	5,445	34	43,945	79
Total Basin	29,040	100	38,500	100	16,125	100	54,625	100
Measured at Great Falls	17,013	63	49,209	126	10,000	161	59,209	110

* The amount of NO_2 + NO_3 Nitrogen in the wastewater was insignificant.

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APPENDIX A

MEAN MONTHLY DATA

POTOMAC RIVER AT GREAT FALLS, MARYLAND

Table A-1

MEAN MONTHLY FLOW, NITROGEN, AND SEDIMENT 1960-1967

POTOMAC RIVER
GREAT FALLS, MD

1960

Month	Mean Flow (Cfs)	NO_2 as NO_2 (mg/l)	NO_2 as NO_2 (#/day)	NO_3 as NO_3 (mg/l)	NO_3 as NO_3 (#/day)	Sediment (#/day)
Jan.	12,270	.007	462.3	.90	59,510	-
Feb.	15,740	.008	678.6	.77	65,313	-
March	16,230	.007	612.2	.97	84,839	-
April	32,940	.001	177.5	.85	150,886	-
May	21,820	.012	1,411.1	.63	74,080	-
June	13,460	.022	1,655.0	.60	45,138	-
July	4,048	.024	523.5	.30	6,544	-
Aug.	3,508	.032	604.9	.38	7,183	-
Sept.	3,946	.029	616.7	.40	8,506	-
Oct.	2,163	.007	81.6	.30	3,497	159,000
Nov.	3,236	.008	96.4	.27	3,253	326,000
Dec.	1,777	.005	47.9	.80	7,661	31,000
Average	10,686	.012	580.0	.60	43,034	-

1961

Jan.	4,948	.020	533.3	.45	11,999	298,000
Feb.	31,150	.015	2,517.0	.75	125,901	59,020,000
March	30,210	.010	1,628.0	.93	151,405	7,350,000
April	34,270	.009	1,662.0	.60	110,808	14,800,000
May	16,470	.006	532.0	.70	62,129	2,070,000
June	7,517	.019	769.0	.42	17,013	538,000
July	3,550	.018	344.0	.44	8,417	175,000
Aug.	2,666	.018	258.0	.22	3,160	70,200
Sept.	2,386	.013	167.0	.13	1,671	585,400
Oct.	2,554	.007	96.0	.29	3,991	688,000
Nov.	3,010	.006	97.0	.37	6,001	113,000
Dec.	7,483	.007	282.0	.57	22,985	1,620,000
Average	12,184	.012	740.0	.49	43,790	7,277,000

Table A-1 (cont.)

1962

Month	Mean Flow (Cfs)	NO_2 as NO_2 (mg/l)	NO_2 as NO_2 (#/day)	NO_3 as NO_3 (mg/l)	NO_3 as NO_3 (#/day)	Sediment (#/day)
Jan.	10,130	.010	545.0	.97	52,952	2,870,000
Feb.	12,210	.007	460.0	1.10	72,379	12,740,000
March	45,900	.008	1,978.0	.63	155,833	41,340,000
April	23,750	.005	639.0	.56	84,472	4,930,000
May	9,891	.010	533.0	.27	14,391	940,000
June	6,527	.013	464.0	.33	11,785	764,000
July	2,911	.010	156.0	.08	1,254	144,000
Aug.	1,709	.010	92.0	.11	1,013	66,100
Sept.	1,402	.006	45.0	.03	226	23,900
Oct.	1,630	.085	746.0	.27	2,371	155,700
Nov.	6,609	.011	391.0	.56	19,944	1,676,000
Dec.	4,183	.011	247.0	.78	17,582	217,000
Average	10,579	.015	525.0	.48	36,184	5,489,000

1963

Jan.	10,450	.012	675.0	.65	36,604	4,260,000
Feb.	5,703	.014	430.0	.80	24,586	265,800
March	45,060	.011	2,670.0	.80	194,262	68,900,000
April	8,432	.008	363.0	.67	30,444	270,000
May	4,982	.011	295.0	.08	2,147	313,400
June	7,015	.041	1,549.0	.31	11,719	1,744,000
July	1,990	.010	107.0	.26	2,788	182,000
Aug.	1,335	.012	86.0	.11	791	34,700
Sept.	1,090	.009	52.0	.09	528	28,300
Oct.	906	.006	29.0	.05	244	26,450
Nov.	3,773	.009	134.0	.22	3,287	439,000
Dec.	4,513	.014	340.0	.52	12,646	354,000
Average	7,854	.013	561.0	.38	26,670	6,401,000

Table A-1 (cont.)

1964

Month	Mean Flow (Cfs)	NO_2 as NO_2 (mg/l)	NO_2 as NO_2 (#/day)	NO_3 as NO_3 (mg/l)	NO_3 as NO_3 (#/day)	Sediment (#/day)
Jan.	13,480	.008	796.0	.84	83,654	13,600,000
Feb.	12,390	.009	600.0	.93	62,095	1,540,000
March	30,660	.008	1,321.0	.80	132,181	27,540,000
April	18,270	.011	1,082.0	.60	59,074	9,190,000
May	15,530	.015	1,263.0	.57	48,011	12,600,000
June	2,915	.015	235.0	.30	4,712	107,000
July	2,310	.008	99.0	.21	2,614	1,230,000
Aug.	1,199	.008	51.0	.16	1,033	7[illegible],100
Sept.	791	.006	25.0	.50	2,131	2[illegible],900
Oct.	2,372	.007	89.0	.07	894	4[illegible],600
Nov.	1,996	.007	75.0	.20	2,151	16[illegible],000
Dec.	5,671	.007	213.0	.70	21,392	49[illegible],000
Average	9,307	.008	487.0	.49	34,995	5,552,000

1965

Jan.	14,900	.021	1,686	.49	39,345	7,060,000
Feb.	19,480	.015	1,574	.87	41,330	11,800,000
March	28,430	.011	1,685	.77	117,971	26,300,000
April	16,820	.011	996	.50	45,321	2,220,000
May	7,914	.013	554	.23	9,809	851,000
June	2,587	.020	278	.20	2,788	300,000
July	1,425	.009	69	.24	1,843	688,000
Aug.	1,127	.005	30	.10	607	135,000
Sept.	1,018	.005	27	.26	1,426	72,700
Oct.	1,586	.006	51	.42	3,589	196,000
Nov.	1,097	.005	29	.35	2,069	28,700
Dec.	1,038	.006	33	.57	3,188	16,200
Average	8,119	.010	584	.42	26,607	4,139,000

Table A-1 (cont.)

1966

Month	Mean Flow (Cfs)	NO_2 as NO_2 (mg/l)	NO_2 as NO_2 (#/day)	NO_3 as NO_3 (mg/l)	NO_3 as NO_3 (#/day)	Sediment (#/day)
Jan.	1,712	.006	55	.93	8,580	142,000
Feb.	13,570	.010	731	1.44	105,305	21,320,000
Mar.	12,460	.015	1,007	1.83	122,878	4,340,000
April	11,790	.012	762	.61	38,757	3,270,000
May	13,990	.029	2,186	.56	42,219	4,720,000
June	2,571	.021	290	.35	4,849	313,000
July	695	.013	48	.24	898	38,700
Aug.	538	.004	11	.14	405	23,900
Sept.	5,712	.020	615	.82	25,241	3,850,000
Oct.	6,726	.009	326	1.05	38,066	1,080,000
Nov.	3,813	.004	82	.33	6,782	548,000
Dec.	7,929	.011	470	1.52	64,961	594,000
Average	6,792	.013	549	.82	38,245	3,354,000

1967

Jan.	9,685	.014	731	2.50	30,505	-
Feb.	10,835	.011	642	1.80	5,121	-
March	35,924	.013	2,517	1.80	348,535	-
April	9,103	.010	491	2.10	103,036	-
May	17,367	.009	842	1.30	121,691	-
June	4,700	.012	304	.86	14,186	-
July	4,532	.027	660	1.10	26,870	-
Aug.	7,364	.017	675	1.30	51,600	-
Sept.	2,813	.009	136	1.30	19,711	-
Oct.	5,529	.008	238	1.30	35,762	-
Nov.	4,296	.008	185	1.30	30,102	-
Dec.	18,031	.011	1,069	1.40	136,062	-
Average	10,848	.012	565	1.47	76,932	-

APPENDIX B

DATA SUMMARIES

Table B-1

POTOMAC RIVER NUTRIENT NETWORK
MONTHLY MEANS--TOTAL PHOSPHOROUS
T. PO_4 AS PO_4
(mg/1)

Station Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Averages
North Branch Potomac River													
Cumberland, Md.	-	.540	.387	.308	.210	.417	.564	.518	.728	.445	.243	.242	.431
Luke, Md. (below Savage River)	-	.050	.040	.068	.033	-	.030	.027	.118	.040	.013	.042	.056
Oldtown, Md.	.770	.718	.273	.305	.272	.457	.708	.703	.930	.428	.480	.576	.532
South Branch Potomac River													
Moorefield, W.Va.	-	.054	.045	.122	.030	.030	.018	.038	.090	.015	.118	.026	.053
Romney, W.Va. (Blue's Beach)	.080	.275	.063	.080	.092	.050	.062	.058	.126	.107	.050	.042	.092
Petersburg, W.Va.	-	.040	.105	.034	.030	.057	.050	.040	.066	.058	.016	.044	.047
Upper Potomac River and Tributaries													
Fort Ashby, W.Va.	.075	.116	.025	.058	.052	.053	.056	.042	.040	.075	.110	.277	.093
Paw Paw, W.Va.	.450	.466	.200	.158	.156	.213	.358	.260	.243	.230	.175	.367	.288
Great Cacapon, W.Va.	-	.118	.028	.095	.068	.387	.080	.022	.017	.045	.030	.107	.093
Hancock, Md.	.250	.282	.135	.213	.182	.100	.148	.110	.123	.168	.190	.303	.188
Williamsport, Md.	.466	.582	.256	.245	.254	.225	.344	.172	.257	.220	.195	.513	.327
Hagerstown, Md.	-	.295	.190	.153	.102	.203	.057	.123	.118	.092	.090	.100	.126
Antietam, Md.	3.386	2.575	1,406	1.620	1.334	1.317	2.145	2.088	.913	2.003	2.550	2.117	1.996
Martinsburg, W.Va.	3.233	2.127	.960	1.473	.912	1.047	1.820	1.710	.550	1.088	1.390	1.250	1.511
Shepherdstown, W.Va.	.283	.481	.163	.203	.097	.092	.088	.090	.115	.155	.135	.060	.199
Brunswick, Md.	.200	.202	.250	.128	.208	.270	.185	.353	.140	.133	.130	.377	.221
Point of Rocks, Md.	.356	.486	.224	.271	.241	.317	.233	.180	.368	.208	.150	.222	.263
North Fork Shenandoah River													
Broadway, Va.	-	-	.020	.478	.023	.023	.046	.140	.112	.044	.036	.064	.112
Middletown, Va.	-	-	-	.095	.056	.109	.113	.106	.135	.072	.146	.058	.100

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Table B-1 (cont.)

Station Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Averages
South Fork Shenandoah River													
Front Royal, Va.	.475	.634	.448	.430	.392	.410	.696	.712	.542	.440	.203	.483	.522
Shenandoah, Va.	-	-	-	.775	.456	.677	.892	.610	.680	.540	.630	.635	.655
Shenandoah River													
Bloomery, W.Va.	.196	.630	.238	.250	.312	.517	.436	-	.375	.397	.175	.286	.356
Monocacy River													
Frederick, Md.	-	.940	.443	.620	.466	.878	2.083	3.570	2.539	.565	.567	.442	1.176
Potomac River													
Caderock, Md.	-	.146	.120	.035	.170	.210	.153	.090	.895	.392	.340	.117	.303
Cabin John, Md.	-	.200	.105	.123	.807	.173	.310	.155	1.305	2.685	.645	.232	.662
Beall Mount, Md.	-	.160	.083	.063	.045	.310	.397	.985	1.395	.263	.872	.445	.490
Travilah, Md.	-	.170	.100	.068	.470	.310	.497	.110	.970	.447	.217	.120	.332
Seneca, Md.	-	.225	.120	.057	.383	.153	.463	.125	.797	.275	.117	.117	.290
Leesburg, Va.	.750	.663	.768	.965	.937	.267	.713	4.535	2.710	.167	.205	.686	1.010
Broad Run, Md.	-	.246	.160	.163	.105	.303	.280	.690	.923	.245	.155	.160	.304
Leesburg, Va.	-	2.670	3.503	4.085	1.480	5.187	7.940	24.395	10.430	1.970	3.325	1.725	5.559
Great Falls, Va.	-	.200	.143	.100	.687	.233	.237	.420	1.057	.365	.933	.080	.397
Arlingwood, Va.	-	.136	.125	.170	.573	6.417	.143	.125	.837	1.425	.130	.125	.877
M St. Bridge, D.C.	.623	.468	.233	.275	.340	.620	.890	.213	.400	.158	.170	.200	.316
Great Falls, Md.	.243	.540	.363	.312	.303	.257	.270	.590	.560	.293	.300	.330	.330
Bladensburg, Md.	1.273	.672	.380	.470	.740	.307	.957	-	.497	1.040	1.793	.514	.753
Occoquan, Va.	.360	.250	.260	.130	.193	.117	.253	-	.245	.235	.230	.204	.225
14th St. Bridge	-	-	.360	.217	.250	.350	-	-	.812	-	-	-	.606
Woodrow Wilson Bridge	3.180	-	1.165	.920	1.090	2.095	-	-	3.844	-	-	-	2.872
301 Bridge	.210	-	-	.280	.350	.280	-	-	.375	-	-	-	.331

Table B-2

POTOMAC RIVER NUTRIENT NETWORK
MONTHLY MEANS--TOTAL PHOSPHORUS
T. PO_4 AS PO_4
(pounds/day)

Station Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Averages
North Branch Potomac River													
Cumberland, Md.	-	12,609	2,511	4,072	2,437	549	472	444	1,140	1,310	1,302	968	2,230
Luke, Md.	-	774	96	636	186	0	15	9	158	65	78	108	201
Oldtown, Md.	1,523	6,779	2,034	2,207	4,087	605	420	490	5,553	1,852	914	2,977	2,551
South Branch Potomac River													
Moorefield, W. Va.	-	204	27	476	44	12	1	3	376	178	68	24	119
Romney, W.Va. Hwy 28	182	9,434	274	1,503	1,453	71	43	32	1,425	354	243	208	1,535
Petersburg, W.Va.	-	460	157	222	113	42	17	14	262	104	54	146	119
Upper Potomac River and Tributaries													
Fort Ashby, W.Va.	17	863	15	100	185	5	1	1	8	43	14	119	147
Paw Paw, W.Va.	949	13,695	3,298	4,097	6,302	674	536	519	6,362	2,588	1,450	4,625	4,299
Great Cacapon, W.Va.	-	536	44	436	334	266	21	6	44	124	35	220	218
Hancock, Md.	1,735	23,327	3,032	10,981	14,694	480	261	242	4,586	4,783	1,080	4,527	6,683
Williamsport, Md.	492	4,545	3,103	646	773	163	154	56	672	195	95	884	1,225
Hagerstown, Md.	-	32,685	3,524	12,603	2,793	1,018	132	256	1,530	1,695	1,714	1,867	3,971
Antietam, Md.	986	1,892	1,956	1,518	1,530	847	909	827	1,401	1,486	1,467	1,015	1,353
Martinsburg, W.Va.	665	1,355	2,872	1,311	1,030	516	531	443	1,062	951	601	990	1,109
Shepherdstown, W.Va.	1,887	72,020	3,330	7,407	4,308	582	262	219	1,330	5,264	2,715	-	15,073
Brunswick, Md.	5	130	642	80	135	29	4	4	127	52	22	165	137
Point of Rocks, Md.	3,471	87,097	8,832	23,112	15,442	3,645	1,045	865	14,130	4,225	3,825	7,529	14,816
North Fork Shenandoah River													
Broadway, Va.	-	-	3	964	25	2	1	1	52	12	77	39	127
Middletown, Va.	-	-	-	431	423	112	59	65	283	176	410	119	219
South Fork Shenandoah River													

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Table B-2 (cont.)

Station Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Averages
Front Royal, Va.	800	5,890	3,037	3,047	3,728	1,190	1,140	1,139	2,828	1,860	1,601	3,576	2,656
Shenandoah, Va.	-	-	-	3,109	2,685	1,620	689	637	2,154	2,956	2,317	3,367	2,002
Shenandoah River													
Bloomery, W.Va.	475	28,746	2,746	2,597	5,365	1,043	985	-	5,959	1,056	951	2,730	5,105
Monocacy River													
Frederick, Md.	-	16,607	1,744	3,070	1,246	747	696	575	9,450	1,060	1,353	1,736	3,385
Lower Potomac River Tributaries													
Cabin John, Md.	-	13	13	9	159	11	22	1	1,523	243	39	18	210
Caderock, Md.	-	3	1	1	4	1	1	1	741	4	3	1	80
Beall Mount, Md.	-	18	5	3	2	7	14	26	3,690	110	395	326	534
Travilah, Md.	-	12	8	4	65	21	30	1	1,133	24	18	7	143
Seneca, Md.	-	109	69	20	389	74	177	9	6,145	125	40	45	774
Leesburg, Va.	77	756	1,187	1,030	864	94	55	48	3,332	192	146	749	791
Broad Run, Md.	-	55	67	30	27	72	38	18	3,703	87	36	38	356
Leesburg, Va.	-	82	104	118	64	204	99	41	407	211	105	89	152
Great Falls, Va.	-	40	34	16	137	20	26	2	2,916	128	72	13	353
Arlingwood, Va.	-	35	10	19	40	595	20	2	8,405	344	9	19	997
M St. Bridge, D.C.	21	289	41	182	137	120	774	4	145	32	22	41	116
Bladensburg, Md.	120	887	67	109	209	51	51	-	743	-	-	-	231
Occoquan, Va.	21	5,224	243	471	1,413	28	50	-	3,959	-	-	-	1,246
Potomac River													
Great Falls, Md.	1,553	81,302	11,132	25,600	26,582	4,056	1,389	1,531	27,935	14,745	5,211	9,226	17,013
14th St. Bridge, D.C.	-	-	60,610	17,795	11,297	-	-	-	16,966	-	-	-	20,512
Woodrow Wilson Bridge	25,947	-	37,489	44,048	46,977	44,925	-	-	44,053	-	-	-	42,489
301 Bridge	2,647	-	-	6,459	10,461	-	-	-	2,321	-	-	-	5,510

Table B-3

POTOMAC RIVER NUTRIENT NETWORK
MONTHLY MEANS--INORGANIC NITROGEN
NO_2-NO_3 AS N
(mg/l)

Station Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Averages
North Branch Potomac River													
Cumberland, Md.	-	.635	.357	.375	.180	.080	.055	.057	.142	.040	.156	.227	.192
Luke, Md. (Above Westvaco)	-	.542	.362	.370	.258	.430	.246	.350	.424	.280	.225	.240	.329
Oldtown, Md.	.404	.446	.552	.292	.265	.235	.397	.446	.636	.175	.190	.316	.378
South Branch Potomac River													
Moorefield, W.Va.	-	.530	.342	.200	.246	.070	.053	.028	.120	.344	.217	.282	.217
Romney, W.Va.	.424	.703	.392	.241	.233	.046	.040	.030	.410	.208	.126	.257	.296
Petersburg, W.Va.	-	2.424	.460	.397	.236	.060	.050	.032	.197	.456	.152	.332	.301
Upper Potomac River and Tributaries													
Fort Ashby, W.Va.	.523	.624	.504	.185	.245	.040	.040	.037	1.060	.605	.040	.426	.396
Paw Paw, W.Va.	.346	.427	.525	.270	.246	.117	.120	.216	.713	.400	.105	.346	.324
Great Cacapon, W.Va.	-	.370	.430	.180	.144	.030	.030	.035	.405	.553	.030	.416	.240
Hancock, Md.	.400	.545	.510	.225	.228	.062	.060	.028	.353	.523	-	.340	.294
Williamsport, Md.	1.458	2.744	1.407	1.805	1.722	1.117	.205	.064	2.026	2.592	1.375	2.880	1.593
Hagerstown, Md.	-	.870	.427	.286	.116	.260	.162	.060	.330	.352	.143	.345	.279
Antietam, Md.	2.473	2.655	1.964	2.260	2.408	2.172	.782	.191	.254	.298	.256	.293	1.429
Martinsburg, W.Va.	2.310	2.580	1.414	1.817	2.080	2.355	1.646	1.840	2.633	3.010	2.075	2.360	2.149
Shepherdstown, W.Va.	1.147	1.148	.919	.703	.362	.250	.110	.060	.280	.585	.355	-	.639
Brunswick, Md.	.837	1.973	1.083	.395	.624	.327	.070	.267	.490	1.102	.500	1.480	.912
Point of Rocks, Md.	.968	1.139	.788	.504	.421	.034	.050	.034	.609	.769	.400	.840	.581
North Fork Shenandoah River													
Broadway, Va.	-	-	.760	.536	.590	.395	.296	.123	1.363	1.273	.000	.862	.773
Middletown, Va.	-	-	-	.403	.574	.185	.040	.032	.890	.842		.477	.402
South Fork Shenandoah River													

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Table B-3 (cont.)

Station Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Averages
Front Royal, Va.	.998	1.103	.796	.547	.592	.226	.053	.595	.443	.786	.587	.826	.641
Shenandoah, Va.	-	-	-	.465	.860	.959	.686	1.248	1.240	1.180	.860	.920	.940
Shenandoah River													
Bloomery, W.Va.	.918	1.125	.829	.550	.384	.040	.030	-	1.025	.797	.455	.780	.654
Monocacy River													
Frederick, Md.	-	2.251	1.515	1.170	1.087	.915	.470	.683	3.820	1.950	1.618	2.572	1.744
Lower Potomac River Tributaries													
Cabin John, Md.	-	.837	.601	.463	.685	.515	.647	.095	.422	.345	.705	.765	.565
Caderock, Md.	-	.700	.425	.291	.516	.536	.287	.080	.340	.232	.812	.505	.450
Beall Mount, Md.	-	1.169	1.272	1.181	1.203	.851	.941	.715	1.324	1.047	1.112	1.385	1.127
Travilah, Md.	-	1.245	1.156	.860	.943	1.266	1.120	.475	.776	.790	.902	1.113	.982
Seneca, Md.	-	1.740	1.418	1.172	1.077	1.768	1.944	.540	1.108	1.040	.927	1.655	1.309
Leesburg, Va.	.391	1.226	1.124	.950	.989	.610	.204	.340	1.480	.775	.537	1.860	.924
Broad Run, Md.	-	.809	.607	.149	.327	1.025	.363	.140	1.276	.682	.505	.965	.692
Leesburg, Va.	-	1.107	.881	2.099	1.180	1.332	1.961	4.270	1.477	.965	.987	.970	1.429
Great Falls, Va.	-	.637	.830	.330	.512	.459	.583	.345	.897	.317	.500	.532	.557
Arlingwood, Va.	-	1.903	1.036	.653	.887	.506	.719	.155	.775	.662	.687	.925	.779
M St. Bridge, D.C.	.947	1.224	.987	.655	.845	1.324	1.180	.586	.796	.714	.566	1.102	.885
Bladensburg, Md.	1.171	1.118	.930	.629	1.112	.666	.521	-	.898	1.272	.573	1.006	.942
Occoquan, Va.	.405	.438	.737	.285	.171	.221	.609	-	.586	.507	.483	.608	.478
Potomac River													
Great Falls, Md.	1.249	1.510	1.237	.737	.678	.256	.271	.010	1.329	1.113	.520	1.525	.923
14th St. Bridge, D.C.	-	-	.936	.526	.389	.305	-	-	.624	-	-	-	.599
Woodrow Wilson Bridge	.628	-	1.009	.500	.422	.112	-	-	1.792	-	-	-	1.240
301 Bridge	.257	-	-	.557	.543	.539	-	-	.108	-	-	-	.338

Table B-4

POTOMAC RIVER NUTRIENT NETWORK
MONTHLY MEANS--INORGANIC NITROGEN
NO_2-NO_3 AS N
(pounds/day)

Station Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Averages
North Branch Potomac River													
Cumberland, Md.	-	14,306	3,256	4,864	2,618	56	34	54	306	135	544	931	2,082
Luke, Md. (Above Westvaco)	-	6,021	1,460	2,283	1,307	256	126	238	490	530	553	653	1,345
Oldtown, Md.	846	6,229	9,082	4,062	5,202	357	254	345	5,003	2,316	425	1,688	3,267
South Branch Potomac River													
Moorefield, W.Va.	-	1,499	272	597	481	31	3	2	393	448	359	318	371
Romney, W.Va.	990	12,716	3,546	5,109	5,276	49	5	12	4,033	1,685	715	1,282	3,655
Petersburg, W.Va.	-	27,935	2,207	4,402	1,900	51	11	10	992	3,196	328	1,012	2,079
Upper Potomac River and Tributaries													
Fort Ashby, W.Va.	99	2,526	472	361	823	2	1	1	357	682	5	201	567
Paw Paw, W.Va.	855	15,654	15,885	9,550	12,010	438	161	444	15,217	7,430	621	4,291	7,791
Great Cacapon, W.Va.	-	1,393	1,293	1,283	1,533	15	4	5	1,022	1,507	17	833	891
Hancock, Md.	2,665	31,430	20,218	12,443	15,977	211	42	43	9,796	10,853	-	5,097	10,271
Williamsport, Md.	1,473	20,071	10,269	3,799	5,954	696	83	16	5,160	1,140	657	4,959	5,317
Hagerstown, Md.	-	59,766	11,061	4,342	6,184	1,235	386	97	5,116	7,739	3,236	5,700	8,853
Antietam, Md.	725	2,439	2,814	2,087	2,760	1,286	383	63	250	223	149	141	1,321
Martinsburg, W.Va.	456	3,069	2,609	1,599	2,389	1,112	472	376	3,800	2,671	884	1,900	1,817
Shepherdstown, W.Va.	5,733	94,563	27,037	23,166	19,899	1,281	366	146	6,023	24,130	16,699	-	27,205
Brunswick, Md.	23	1,271	1,658	260	566	45	7	8	1,240	499	77	757	568
Point of Rocks, Md.	8,952	119,816	38,561	33,994	30,173	335	69	77	30,153	17,840	10,483	27,856	26,959
North Fork Shenandoah River													
Broadway, Va.	-	-	143	1,290	748	33	2	1	2,623	412	1,204	515	718
Middletown, Va.	-	-	-	2,338	3,180	103	18	17	1,260	2,760	847	1,166	1,300
South Fork Shenandoah River													
Front Royal, Va.	1,629	11,257	6,588	3,406	5,113	578	56	896	2,286	3,451	4,277	5,879	3,994

Table B-4 (cont.)

Station Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Averages
Shenandoah, Va.	-	-	-	3,513	4,440	1,414	594	1,222	1,181	6,552	3,551	4,683	2,688
Shenandoah River													
Bloomery, W.Va.	2,185	19,344	9,273	4,213	7,702	63	40	-	15,545	4,226	2,462	7,363	6,714
Monocacy River													
Frederick, Md.	-	29,654	7,702	5,165	3,106	348	144	26	27,747	3,712	5,335	10,587	8,661
Lower Potomac River and Tributaries													
Cabin John, Md.	-	57	67	33	106	35	40	1	373	79	49	58	89
Caderock, Md.	-	12	7	5	13	3	3	1	172	17	8	6	26
Beall Mount, Md.	-	125	82	52	71	25	27	21	1,406	575	659	918	434
Travilah, Md.	-	80	91	48	95	99	47	6	322	103	63	68	103
Seneca, Md.	-	766	651	392	684	901	514	47	3,581	1,066	770	659	974
Leesburg, Va.	41	2,392	2,000	978	879	185	13	3	3,913	1,337	501	1,892	1,308
Broad Run, Md.	-	215	224	36	93	385	28	4	4,471	550	183	240	583
Leesburg, Va.	-	41	37	66	64	47	36	25	397	104	31	30	90
Great Falls, Md.	-	130	201	52	125	44	53	1	1,621	326	64	97	280
Arlingwood, Va.	-	209	108	61	79	37	106	3	4,592	1,257	55	176	691
M St. Bridge, D.C.	81	739	197	342	295	79	925	14	287	162	73	255	274
Bladensburg, Md.	106	920	131	140	259	58	94	-	1,141	-	-	-	409
Occoquan, Va.	5,705	-	37,410	38,393	20,936	2,559	-	-	1,494	-	-	-	2,253
Lower Potomac River													
Great Falls, Md.	4,249	159,375	57,188	54,200	46,630	4,432	1,216	25	82,051	55,163	9,819	57,524	49,209
14th St. Bridge, D.C.	-	-	26,020	41,962	20,239	8,968	-	-	27,087	-	-	-	26,538
Woodrow Wilson Bridge	-	-	-	-	-	-	-	-	-	-	-	-	23,812
301 Bridge	-	-	-	-	-	-	-	-	-	-	-	-	8,433

Table B-5

SUMMARY OF WASTEWATER TREATMENT PLANT NUTRIENT SURVEY DATA
POTOMAC RIVER BASIN

Facility	Average Flow	T. PO_4 as PO_4			NO_3 as N			NO_2 as N			TKN as N		
	(mg/l)	Inf. (mg/l)	Eff. (mg/l)	Removal (%)	Inf. (mg/l)	Eff. (mg/l)	Removal (%)	Inf. (mg/l)	Eff. (mg/l)	Removal (%)	Inf. (mg/l)	Eff. (mg/l)	Removal (%)
Bel-Air - Pinto, Md.	0.030	50.932	24.774	51.47	.135	.618	-357.77	.0126	.9237	-7320.95	26.031	11.485	55.87
Bowling Green, Md.	0.206	53.677	37.343	30.41	.091	.062	31.86	.0185	.0154	16.75	17.256	19.130	-10.85
Celanese Corp. (Amcelle, Md.	2.300	125.886	81.333	35.39	.385	.187	51.42	.0149	.0012	91.94	4.729	4.953	-4.73
Cresaptown, Md.	0.070	61.092	40.801	33.21	.091	.321	-252.74	.0522	.0529	-1.34	24.506	24.059	1.82
Cumberland, Md.	9.300	22.285	19.646	11.84	.234	.215	8.11	.0277	.0425	-53.42	17.849	14.444	19.07
Frederick, Md.	4.600	40.180	32.317	19.56	.130	.063	51.53	.0248	.0037	85.08	20.943	18.648	10.78
Front Royal, Va.	1.200	37.144	25.488	31.38	.061	.167	-173.77	.0092	.0295	-220.65	19.249	17.551	8.82
Hagerstown, Md.	5.852	41.385	38.126	7.87	.073	.044	39.72	.0184	.0105	42.93	22.087	15.636	29.20
Staunton, Va.	2.600	32.407	28.515	12.00	.078	2.507	-3114.10	.1103	.5747	-421.03	29.323	17.584	40.03
Waynesboro, Md.	2.715	37.522	15.510	58.66	.135	3.067	-2171.85	.0072	.2675	-3615.27	23.908	10.688	55.29
Westernport, Md.	21.720	12.901	8.534	33.85	.387	.131	66.14	ND	ND	ND	2.681	1.756	34.50
Williamsport, Md.	0.233	51.742	64.479	-24.16	.085	.294	-245.88	.0177	.0889	-402.25	30.197	26.542	5.48
Winchester, Md.	4.200	26.725	17.778	33.47	.084	.543	-546.42	.0655	.0530	19.08	18.788	17.732	5.62

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